Appendix F: Climate impacts and adaptation actions for American marten

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the American marten (*Martes americana*).

Figure F.1. American marten.

The American marten is a boreal species with wide distribution among forest and subalpine habitats of northern North America. In the transboundary region of Washington and British Columbia, the marten's late-successional forest habitat exhibits relatively high connectivity, though barriers to movement are presented by both natural factors (e.g., low-elevation forests, grasslands and shrub-steppe) and human factors (e.g., highways, dams, towns, and railways).[2] Significant movement barriers are present along major highways (e.g., US Interstate 90) (Appendix F.1).[2]

Future climate change may present additional challenges and needs for marten habitat connectivity.[3-4] First, climate change may impact marten core habitat and dispersal corridors in ways that may make them more or less permeable to movement. Second, existing marten core habitat and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in marten distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for marten habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on marten habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary marten habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence marten habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix F.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The marten conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to marten habitat connectivity.

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[i] This report is Appendix F of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on marten connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

Key impacts on transboundary marten habitat connectivity identified via this approach include changes in areas of climatic suitability for marten, changes in forest habitat, changes in disturbance regimes, and declining amount and duration of snowpack.

Changes in areas of climatic suitability

Climate change may impact marten habitat connectivity by changing the extent and location of areas of climatic suitability for marten; this may render some existing core habitat areas and corridors unsuitable for marten, and/or create new areas of suitability. Climatic niche models provide estimates of species' current and projected future areas of climatic suitability, and are available for the marten for the 2080s based on two CMIP3 Global Circulation Models (GCMs) (CGCM3.1(T47) and UKMO-HadCM3[ii]) under the A2 (high) carbon emissions scenario[iii] (Appendix F.3).

For both climate models, low-elevation habitat areas are projected to become less climatically suitable for the marten, while higher elevation locations in the Coastal and Rocky Mountains are projected to become more suitable. Projected change is mild under the CGCM3.1(T47) scenario, with only the lowest elevations becoming unsuitable and the vast majority of mid- to high- elevation habitat remaining climatically stable. However, under the UKMO-HadCM3 scenario, loss of climatically suitable habitat is widespread. Loss of suitable habitat is especially severe in the North Cascades, with most stable habitat remaining at either very high elevations or on the east side of the mountains. Mid-elevation suitable habitat adjacent to the Okanagan Valley contracts significantly, leaving a few large but isolated patches of stable habitat (Appendix F.3). Because core habitat tends to be at higher elevations, corridors may be at greater risk than core habitat.

[ii] CGCM3.1(T47) and UKMO-HadCM3 are two different Global Circulation Models (GCMs) used to project future changes in climate. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

Changes in forest habitat

Marten inhabit late-successional, cold-moist and cold-dry forest.[2] Changes in the distribution and quality of forest habitats in the transboundary region could therefore be expected to affect marten core habitat and corridors.

Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models (Appendix F.4).[iv] Both types of models are based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[ii] Both models also use the A2 (high) emissions scenario.[iii] Both mechanistic and climatic niche vegetation models project that forest cover will expand into high-elevation alpine regions (Appendix F.4), which could benefit marten by expanding its range to higher elevations. However, mechanistic models project a significant expansion of cool forest into higher elevations, with a net loss of cold forest at mid-elevations (Appendix F.4). The implications of these projections depend on how strongly marten prefer cold versus cool forest and how meaningful the difference in the model definitions of these forest types is for marten.

Changes in disturbance regimes

Climate change may affect marten habitat connectivity via increasing frequency and severity of summer drought (Appendix F.6: Summer Soil Moisture, July - September), increasing risk of wildfires (Appendix F.6: Days with High Fire Risk), and changing pest and pathogen dynamics. Climate models for the transboundary region consistently project hotter and drier summers. Forest health may be reduced if summer drought intensifies, as suggested by summer soil moisture projections. A longer fire season and increase in area burned could also affect forest habitat.[11] In addition, insect pests can adversely affect forest health. At low levels, insect pests such as spruce budworm or mountain pine beetle can help create snags and tree cavities that provide important breeding habitat for marten. However, if insect populations reach epidemic levels, tree mortality can lead to widespread forest loss. In Washington State, probability of mountain pine beetle survival is projected to decline at lower elevations, but to increase at high elevations (Appendix F.5). Finally, runoff from extreme precipitation events (Appendix F.6: Number of Heavy Precipitation Days; Average Precipitation Intensity) could scour riparian forests and remove trees and shrubs. This would reduce the quality of riparian areas, which are frequently used by marten as movement corridors. Together, these projected changes in disturbance regimes could affect marten habitat connectivity by reducing the amount and/or quality of core forest habitat and movement corridors.

Declining amount and duration of snowpack

Projected declines in the amount and duration of snowpack (Appendix F.6: Spring (April 1) Snowpack; Late Spring (May 1st) Snowpack; Snow Season Length) may affect marten habitat connectivity by reducing the snow cover used by marten for hunting and thermal insulation, and allowing people earlier access to forest habitat for recreational use, timber harvesting, and trapping. Both April 1st and May 1st

[iv] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

snowpack levels are projected to decline throughout much of the study area, with severe declines at lower elevations by the end of the century. The length of the snow season is also projected to decline, but declines in snow season length are most severe at mid to high elevations, with little change at low elevations.

Adaptation responses

After identifying potential climate impacts on marten habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix F.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on marten habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in marten distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on marten habitat connectivity

Actions to address the potential for climate change to impact connectivity through more frequent and severe wildfires include:

- Using fuel reduction techniques and prescribed burns to create fire breaks and reduce the risk of catastrophic wildfires and pest outbreaks that could result in broad-scale loss of marten habitat and corridors. Vegetation management strategies should simultaneously aim to preserve sufficient cover (e.g., understory and woody debris) for marten (i.e., thinning and other fuel reduction strategies should also consider stand diversity and habitat goals).
- Using some degree of fire suppression in cool, moist forests with long fire return intervals, such as those used by marten. In contrast to drier, low elevation forests, suppressing fire in cool, moist forests is less likely to result in increased fuel loads over time (which can lead to subsequent increased fire risk years later).
- Incorporating projections and observations of changes in the length of the snow season, evapotranspiration, soil moisture deficits, and the timing of precipitation to inform the timing of fire prevention techniques as conditions change, in order to maximize their safety and effectiveness.
- Prioritizing implementation of above actions within key marten corridors (Appendix F.1), to ensure that critical linkages are not lost to severe fires.

Actions to address the potential for climate change to impact connectivity through declines in the amount and duration of snowpack include:

- Using forest practices that promote snowpack retention (e.g. snow fences) at elevations used by marten that are projected to experience the greatest decreases in snowpack. Consider prioritizing such efforts within important marten core habitat areas and corridors.
- Ensuring that moisture and snowpack retention practices (when implemented) are compatible with other forest management practices that balance the need for fire and natural resource management with the need for sufficient horizontal cover for marten.
- Identifying areas where snowpack is most likely to persist in the future (Appendix F.6), such as north-facing slopes and topographically shaded areas (e.g., canyons). Consider directing moisture and snowpack retention efforts to these areas, and prioritize them when managing for marten core habitat and corridors.

Actions to address the potential for climate change to impact connectivity through increased potential for human-marten interactions due to declines in snowpack include:

- Managing road access and all-terrain-vehicle activity within marten core habitat areas and corridors to limit impacts from earlier or high-intensity recreational use, timber harvesting, and trapping. Proposals to develop new roads at higher elevations should be carefully evaluated to determine impacts on marten habitat and connectivity.
- Monitoring and evaluating the impacts of changes in the timing of road openings and closures on marten reproduction and movement.

Enhancing connectivity to facilitate range shifts

Actions that may help the marten adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- Maintaining and restoring corridors between areas of declining climatic suitability for marten and areas of stability or increasing suitability (Appendix F.3).
- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors,[7] Appendix F.1), to ensure that marten have the ability to disperse into cooler, higher elevation habitats as the climate warms.
- Planning the placement, orientation, and shape of reserve patches to maximize connectivity, span climatic gradients, and cross low-elevation valleys. As part of this, ensure that when clear cuts are made in forested marten core habitat and corridors, reserve patches are connected with corridors.
- Focusing habitat retention efforts on riparian habitats, which span climatic gradients and are frequently used by marten as movement corridors.

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Existing marten core habitat areas and corridors (Appendix F.1), which will be important for maintaining marten populations under current climate, and facilitating marten response to future change (regardless of whether future declines in climatic suitability occur within the current corridor network).
- Climate-gradient corridors (Appendix F.1), which may help the marten shift its range into cooler habitats as climate warms.
- Riparian areas, which span climatic gradients and are frequently used by martens as movement corridors. Martens prefer to travel along riparian corridors where shaded streams are cooler and moister than the surrounding landscape.
- Highways, especially those that cross the Cascade Range (e.g., Highway 3 and US Interstate 90) may present dispersal barriers. For example, Highway 3 cuts east-west through E.C. Manning Provincial Park and may create a dispersal barrier for south-north movement through the North Cascades; if there is evidence that the road creates a barrier, it could be a candidate for a crossing.

Policy considerations

Forest management

Actions for addressing climate impacts on marten habitat connectivity through forest management include:

- Managing forestry activities to ensure that forest canopy cover remains continuous throughout marten corridors, and that large trees, old snags, and tree cavities remain present.
- Securing water rights to maintain moisture in riparian areas and wetlands that provide movement corridors and refugia through otherwise unsuitable habitat.
- Closely managing all-terrain-vehicle use, timber harvest, and trapping within climate-resilient marten core habitat areas (see Additional Research, below).
- Investigating whether having multiple priority species affected in the same area can lead to greater pressure to change management practices if cumulative impacts can be demonstrated.
- Coordinating stewardship and management activities with provincial and local governments, NGOs, tribes and First Nations, and especially with landowners.
- Reviewing and implementing existing guidance and plans relating to marten habitat management. Evaluate existing recommendations for opportunities to address climate impacts.

Transportation Planning

Actions for addressing climate impacts on marten connectivity through transportation planning include:

- Coordinating with transportation agencies to evaluate appropriate management responses to potential changes in seasonal road openings and closings within high value marten habitat as snow conditions change, and higher elevation habitat potentially becomes more accessible to people.
- Coordinating with transportation agencies to ensure that new roads do not negatively impact climate-gradient corridors, or climate-resilient marten core habitat and corridors (see Additional Research, below). When new roads are inevitable, mitigate barrier effects by incorporating crossing structures into road design.

Research needs

Future research that could help inform marten connectivity conservation under climate change includes:

- Developing transboundary fire models. These models could improve assessment of potential impacts, and direct fire management activities toward core habitat areas and corridors identified as being at high fire risk.
- Developing transboundary pest models (e.g., mountain pine beetle, spruce budworm, and western pine beetle). These models could improve assessment of potential impacts, and direct forest health activities toward core habitat areas and corridors identified as being at high risk of insect or pathogen outbreaks.
- Developing fine-scaled, transboundary riparian models. These could help identify high quality riparian corridors that could facilitate movement despite general regional warming.

- Gathering additional empirical data on transboundary marten movement to validate and improve existing corridor models.
- Identifying potential climate impacts on specific core habitat areas and corridors. Overlay projected changes in climate with existing marten corridor networks to quantify expected impacts on specific areas within the network. This may help direct adaptation actions to appropriate areas.
- Identifying climate resilient marten core habitat areas and corridors. Overlay corridor networks (Appendix F.1) with climatic niche models (Appendix F.3) and projected changes in vegetation (Appendix F.4), mountain pine beetle survival (Appendix F.5), and climate variables (Appendix F.6); core areas and corridors within the current range that are projected by multiple models to retain suitable climatic conditions and vegetation, have low risk of future mountain pine beetle outbreaks, and to see the least change in relevant climatic variables, may be most likely to be resilient. Climate-resilient core habitat areas and corridors may be used to identify priority areas for the adaptation actions described above.
- Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or improving climatic suitability. Use climatic niche models (Appendix F.3) and vegetation projections (Appendix F.4) to identify potentially stable or improving locations. Use corridor models (Appendix F.1) and/or conduct new modeling to identify potential corridors for connecting vulnerable marten core habitat areas to areas projected to remain climatically suitable or become newly suitable.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[v]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[vi] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

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[v] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[vi] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices F.1-6

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For American marten, these materials include:

Appendix F.1. Habitat connectivity models
Appendix F.2. Conceptual model of habitat connectivity
Appendix F.3. Climatic niche models
Appendix F.4. Projected changes in vegetation communities
Appendix F.5. Projected changes in probability of mountain pine beetle survival
Appendix F.6. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. F.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.

ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).

iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

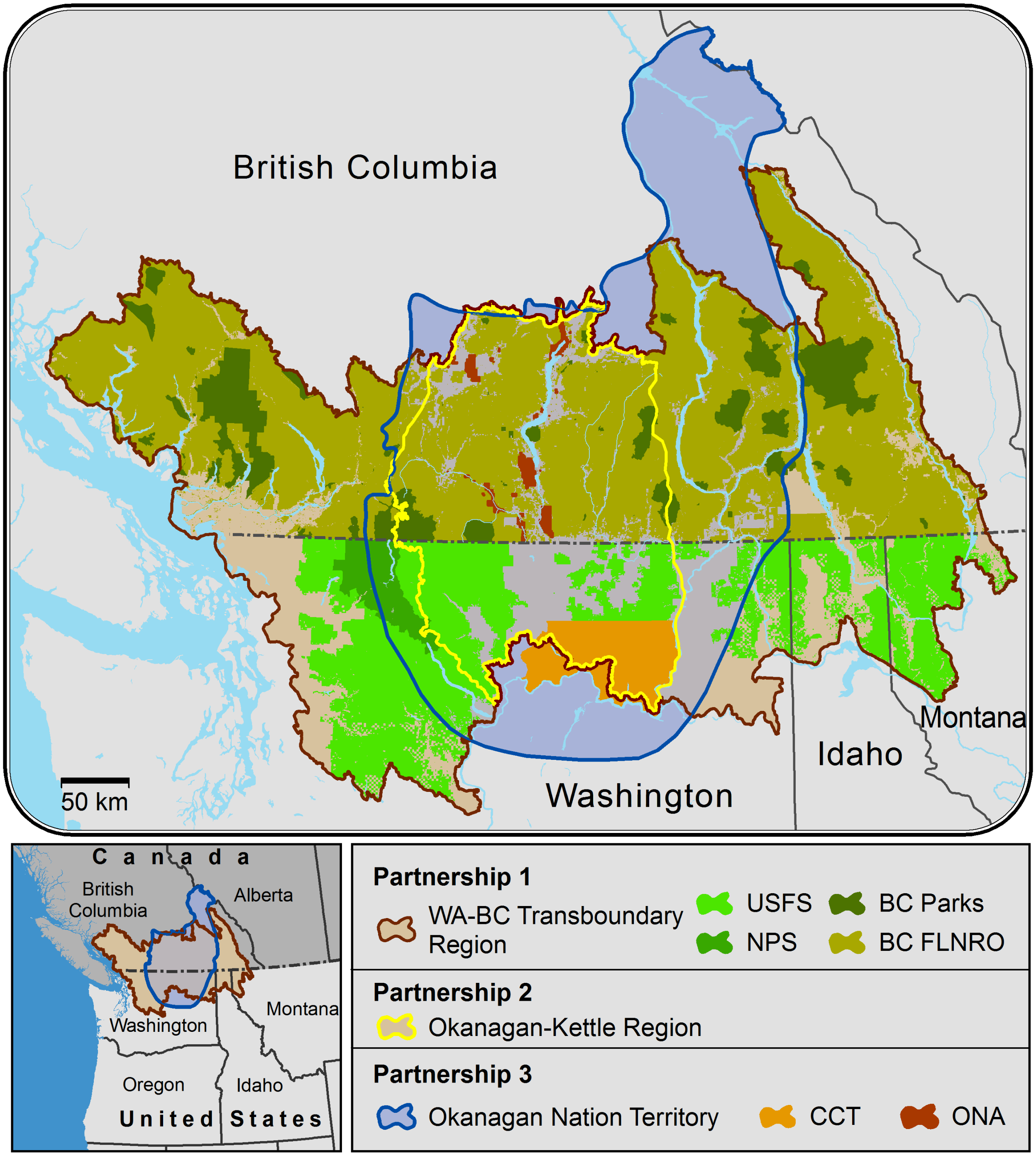


Figure F.2. Project partners and assessment areas.

Appendix F.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vii] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

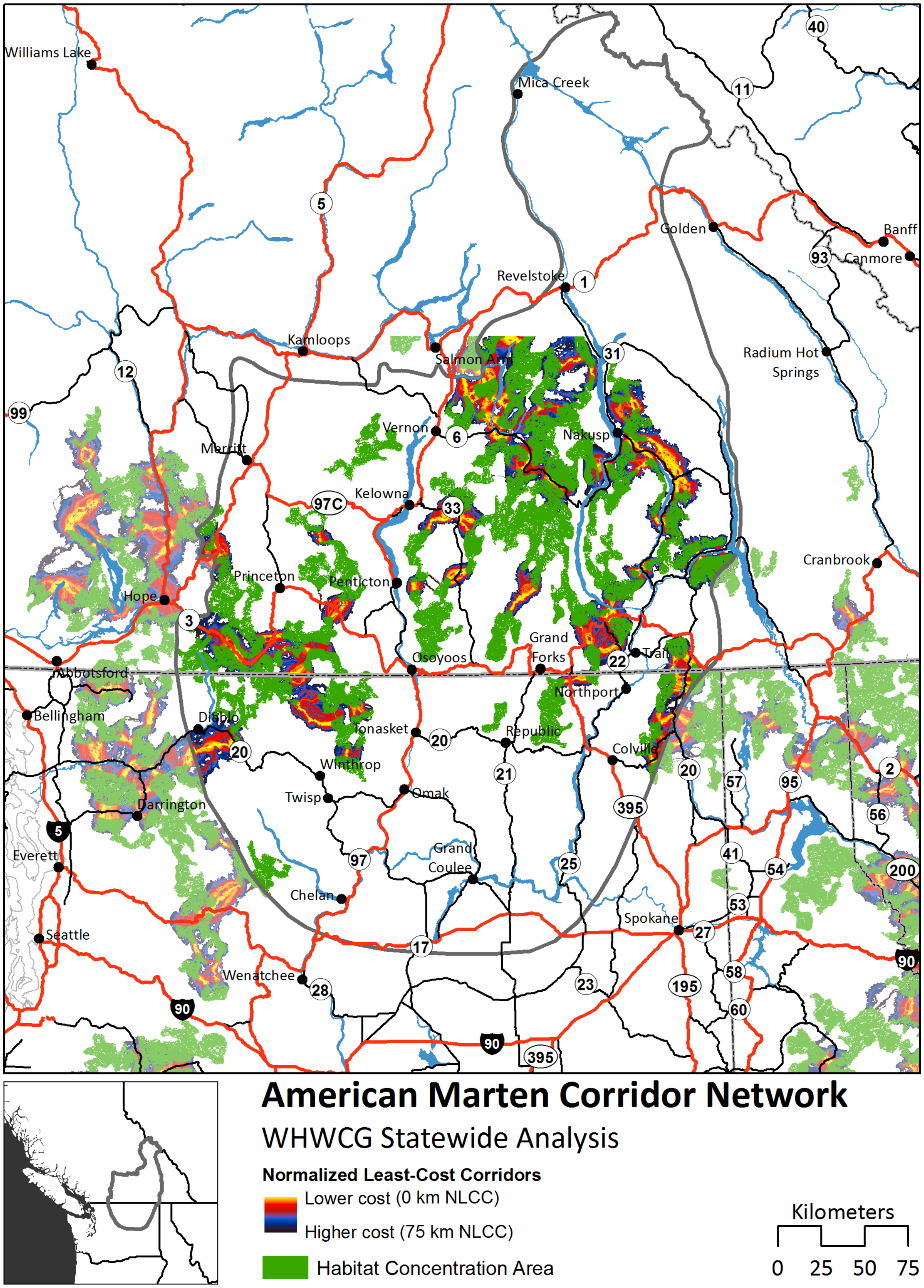
a) **WHCWG Statewide Analysis: American Marten Corridor Network.[2]** This map shows Habitat Concentration Areas (HCAs, green polygons), which are large, contiguous areas featuring little resistance to species movement; and corridors (glowing yellow areas) connecting HCAs, modeled using least cost corridor analysis. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).[7]** This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vii] For detailed methodology and data layers see http://www.waconnected.org.

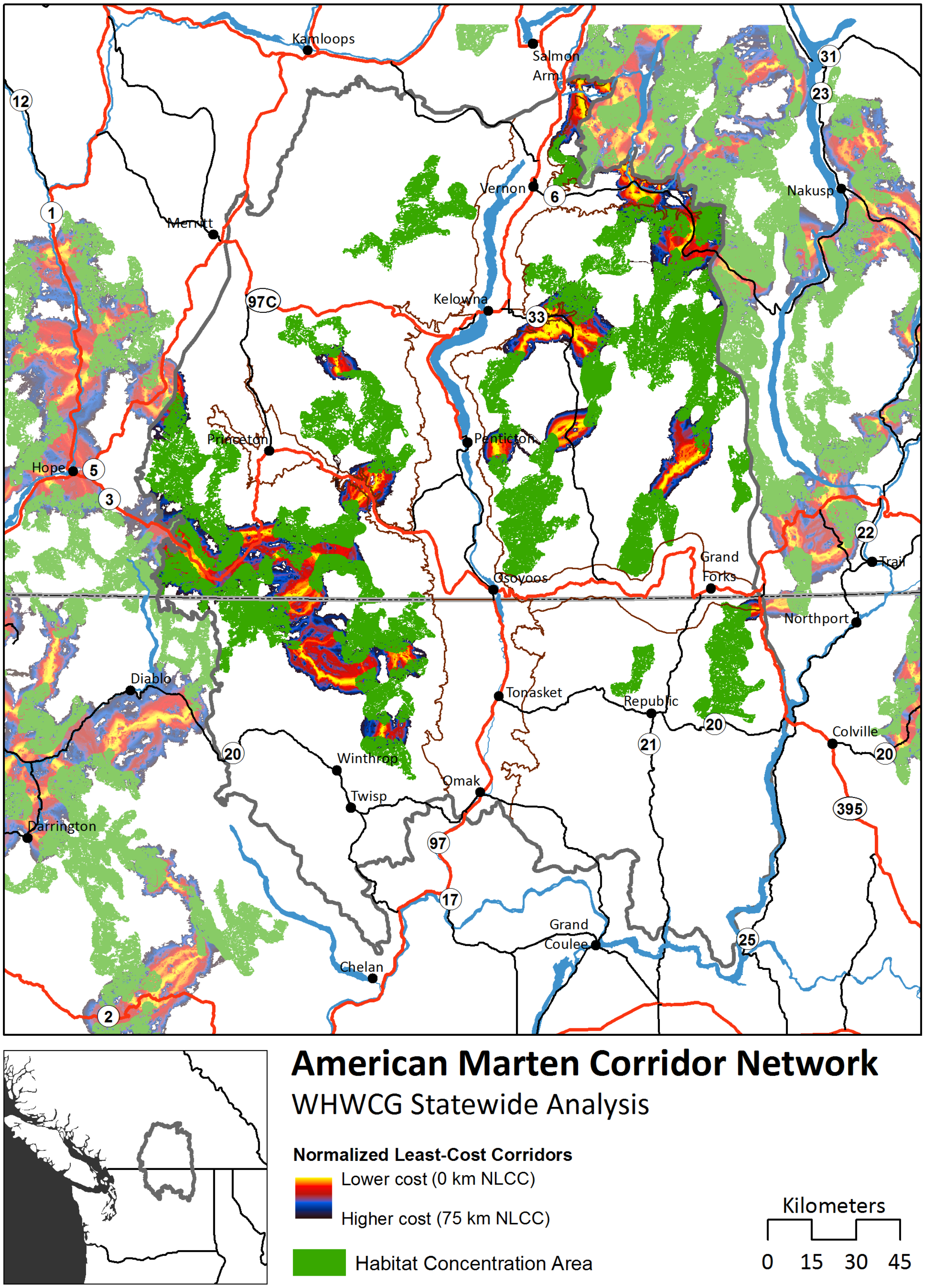
Appendix F.1a. WHCWG Statewide Analysis: American Marten Corridor Network

i) Extent: Okanagan Nation Territory



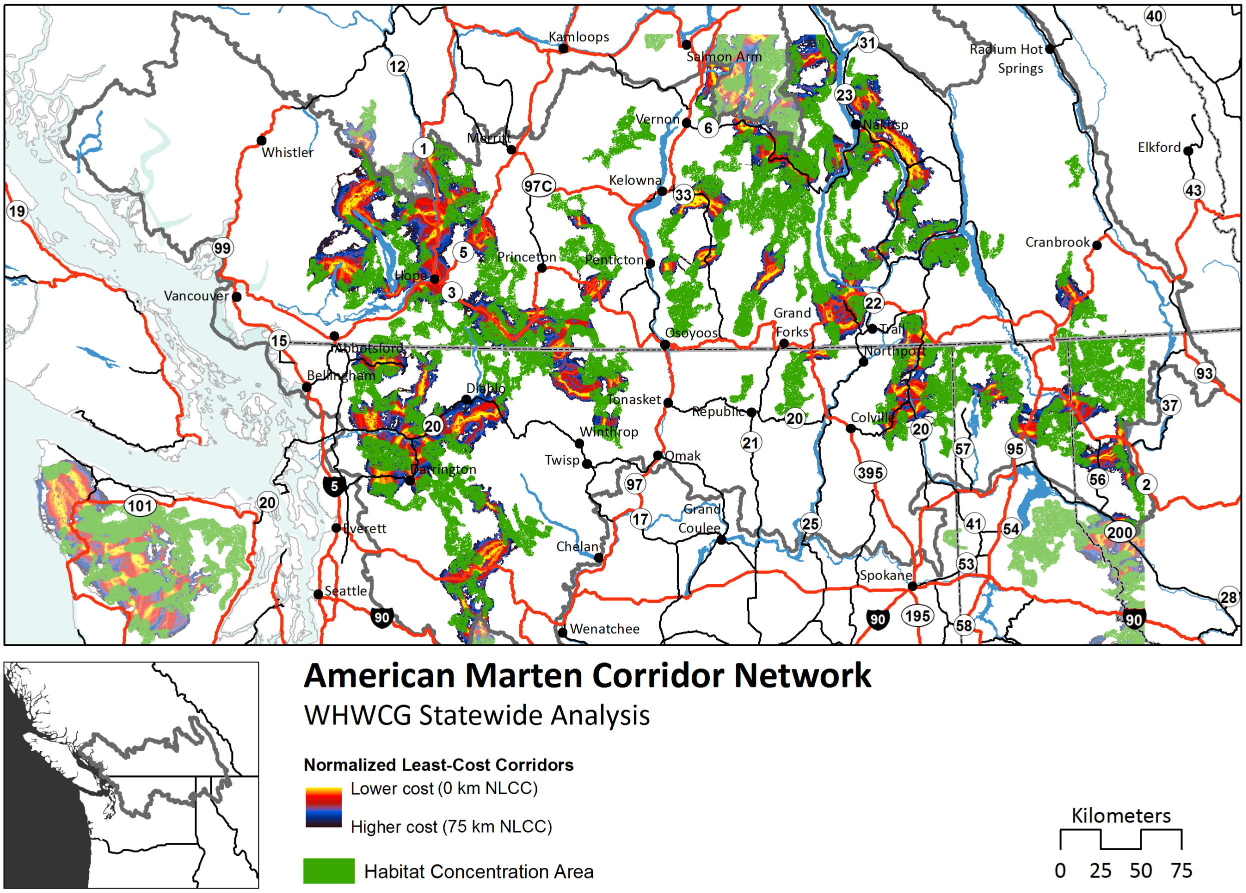
Appendix F.1a. WHCWG Statewide Analysis: American Marten Corridor Network

ii) Extent: Okanagan-Kettle Region



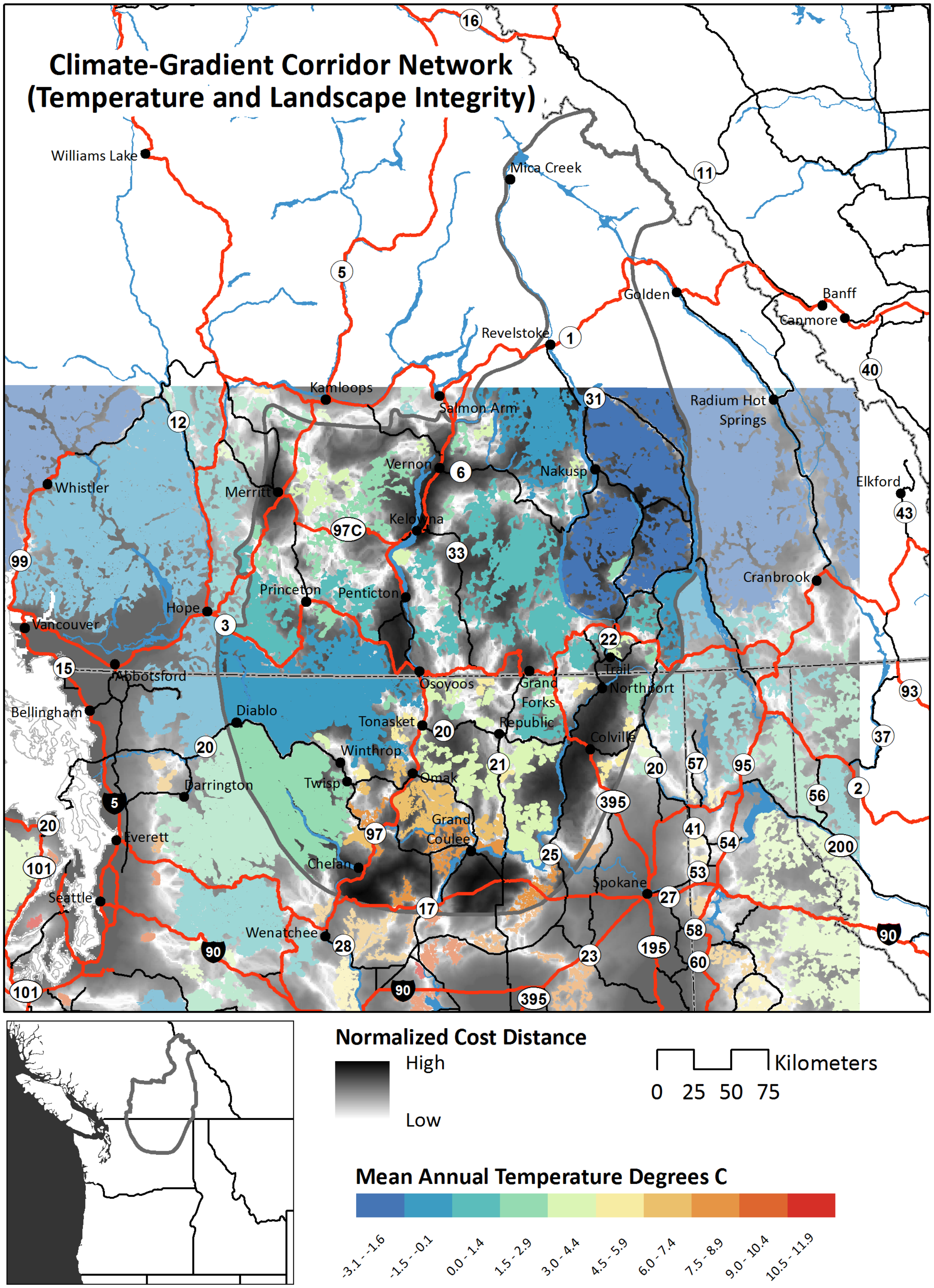
Appendix F.1a. WHCWG Statewide Analysis: American Marten Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region



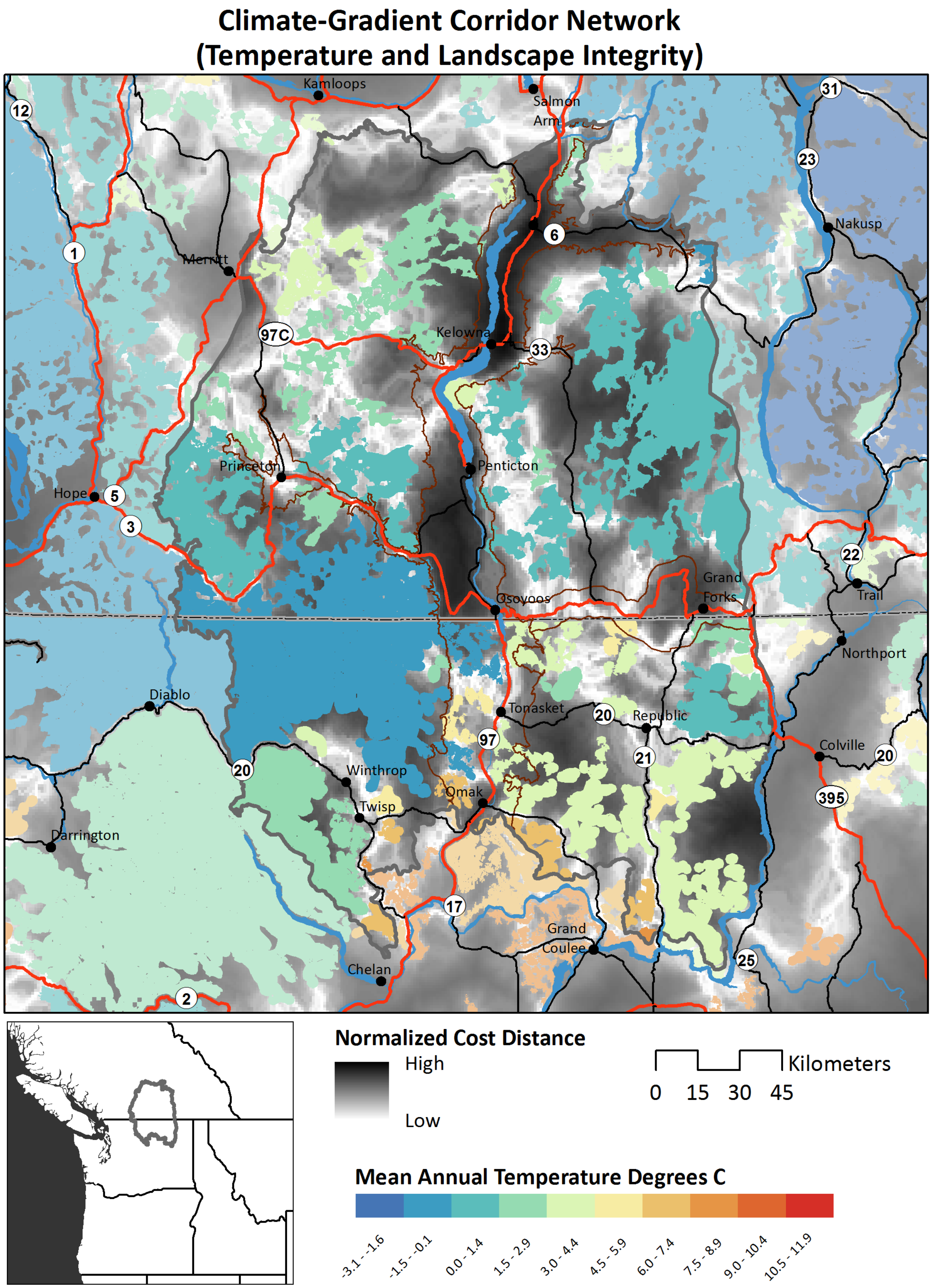
Appendix F.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

i) Extent: Okanagan Nation Territory



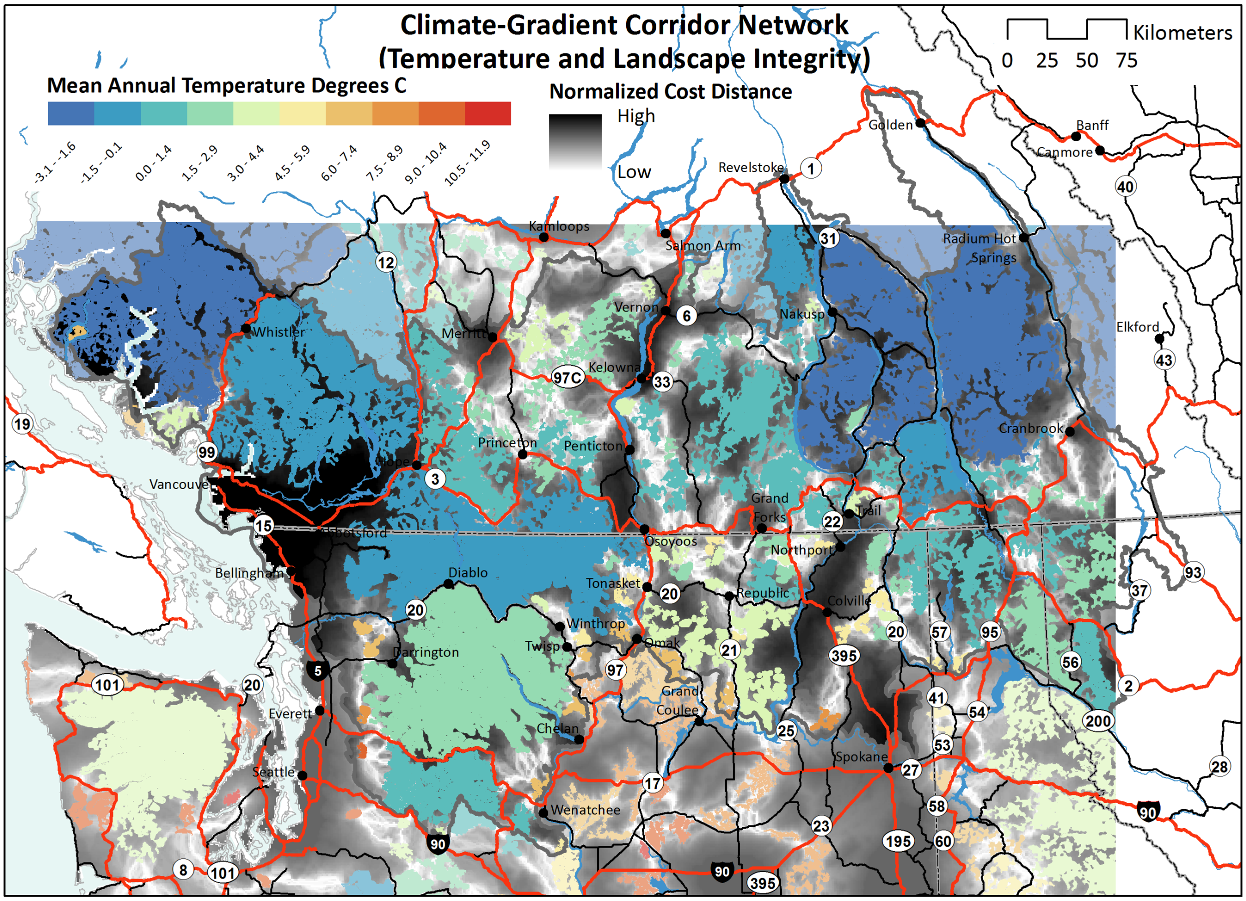
Appendix F.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

ii) Extent: Okanagan-Kettle Region



Appendix F.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix F.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary American marten habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence American marten habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] American marten conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to American marten habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the marten conceptual model included:

- Cliff Nietvelt, BC FLNRO
- Rich Weir, Environment Canada

Key references used to create the marten conceptual model included:

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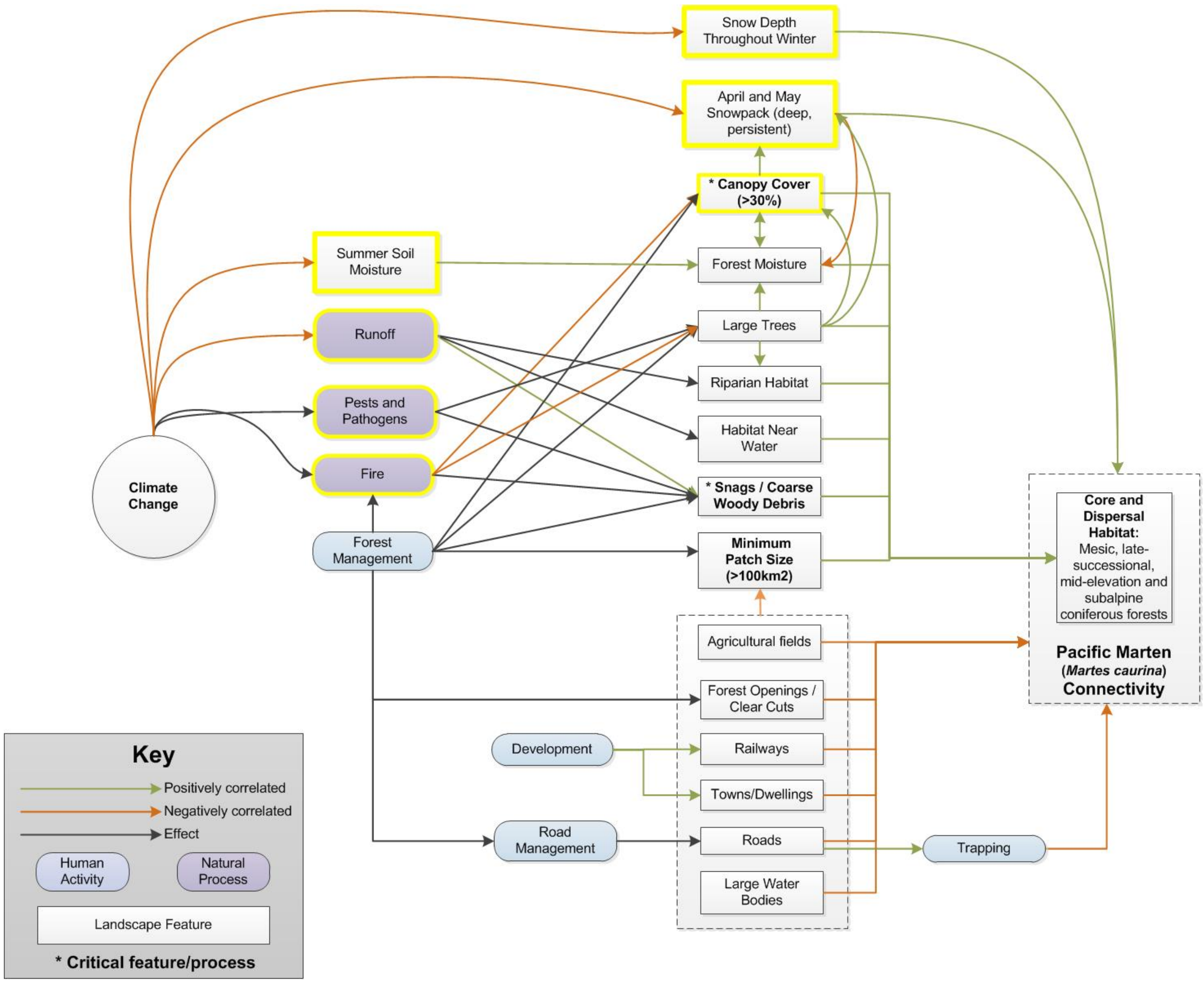
Appendix F.2. Conceptual Model of American Marten Connectivity



Appendix F.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[viii] Both models use the A2 (high) emissions scenario.[ix] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[x]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

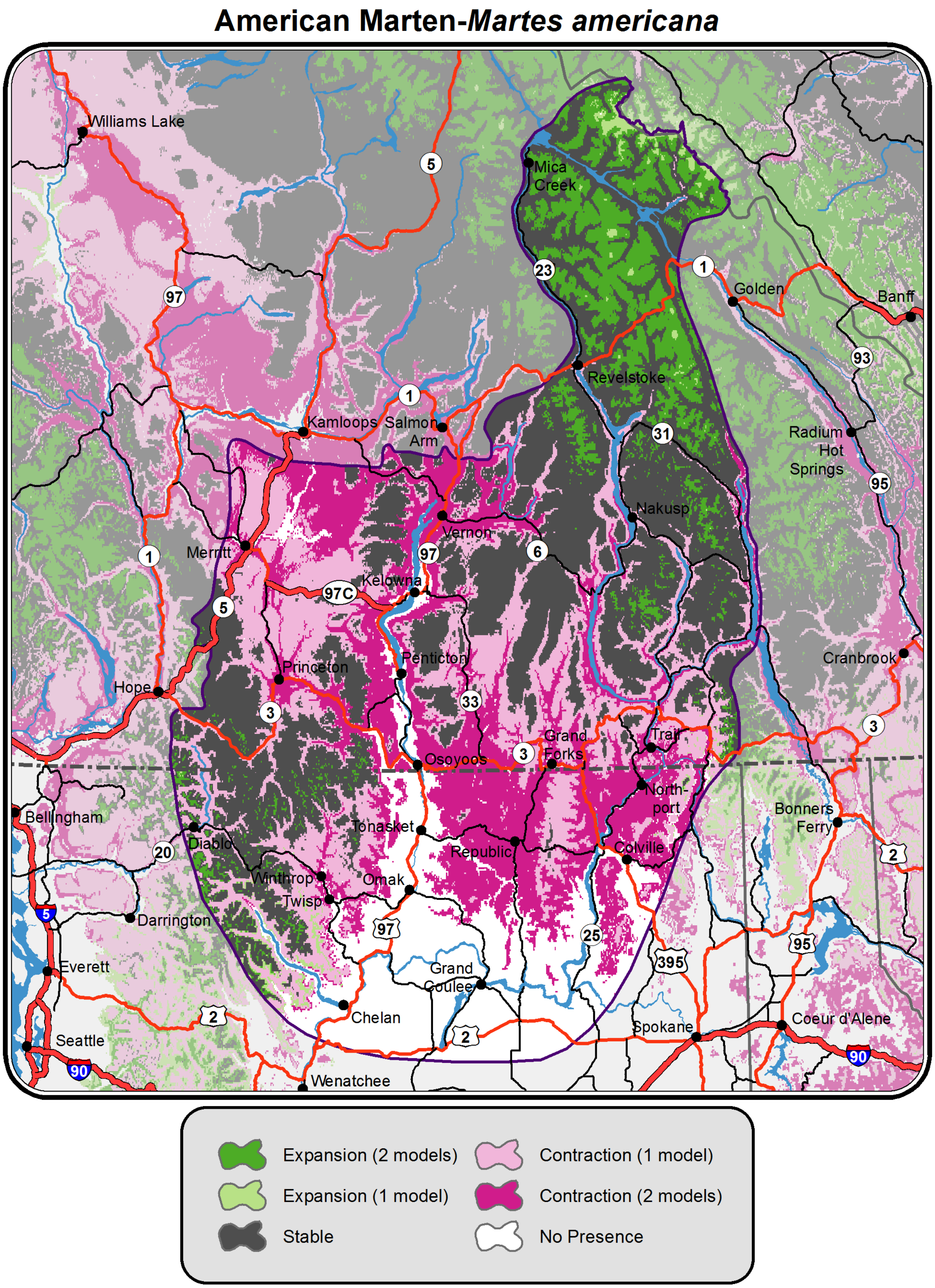
[viii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[ix] Emissions scenarios were developed by climate modeling enter for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21[st] century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[x] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix F.3. American Marten Climatic Niche Model

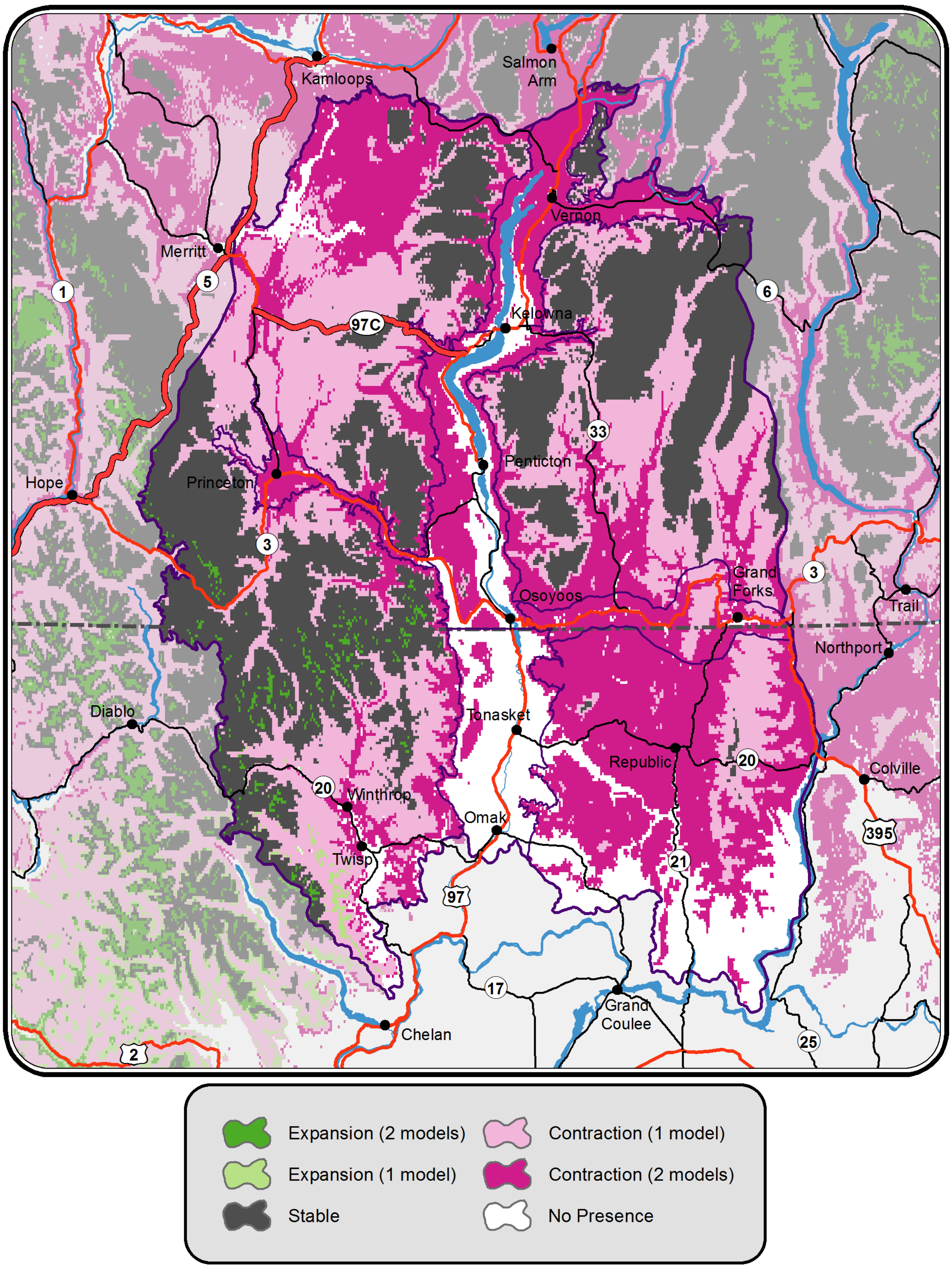
i) Extent: Okanagan Nation Territory



Appendix F.3. American Marten Climatic Niche Model

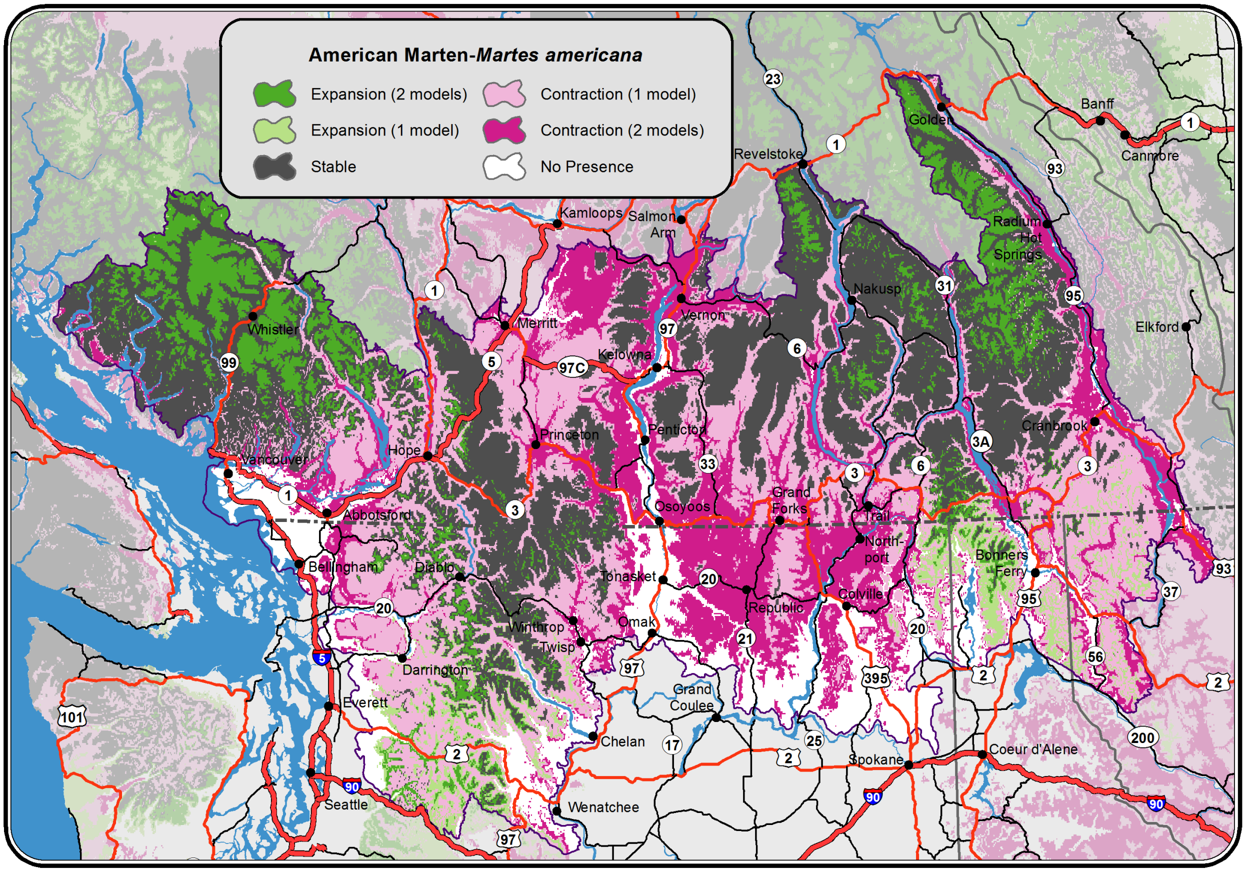
ii) Extent: Okanagan-Kettle Region

American Marten-*Martes americana*



Appendix F.3. American Marten Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix F.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[xi] Both models also use the A2 (high) emissions scenario.[xii]

a) **Biome Climatic Niche Vegetation Model.[xiii]** This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.[xiv]** This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[xi] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

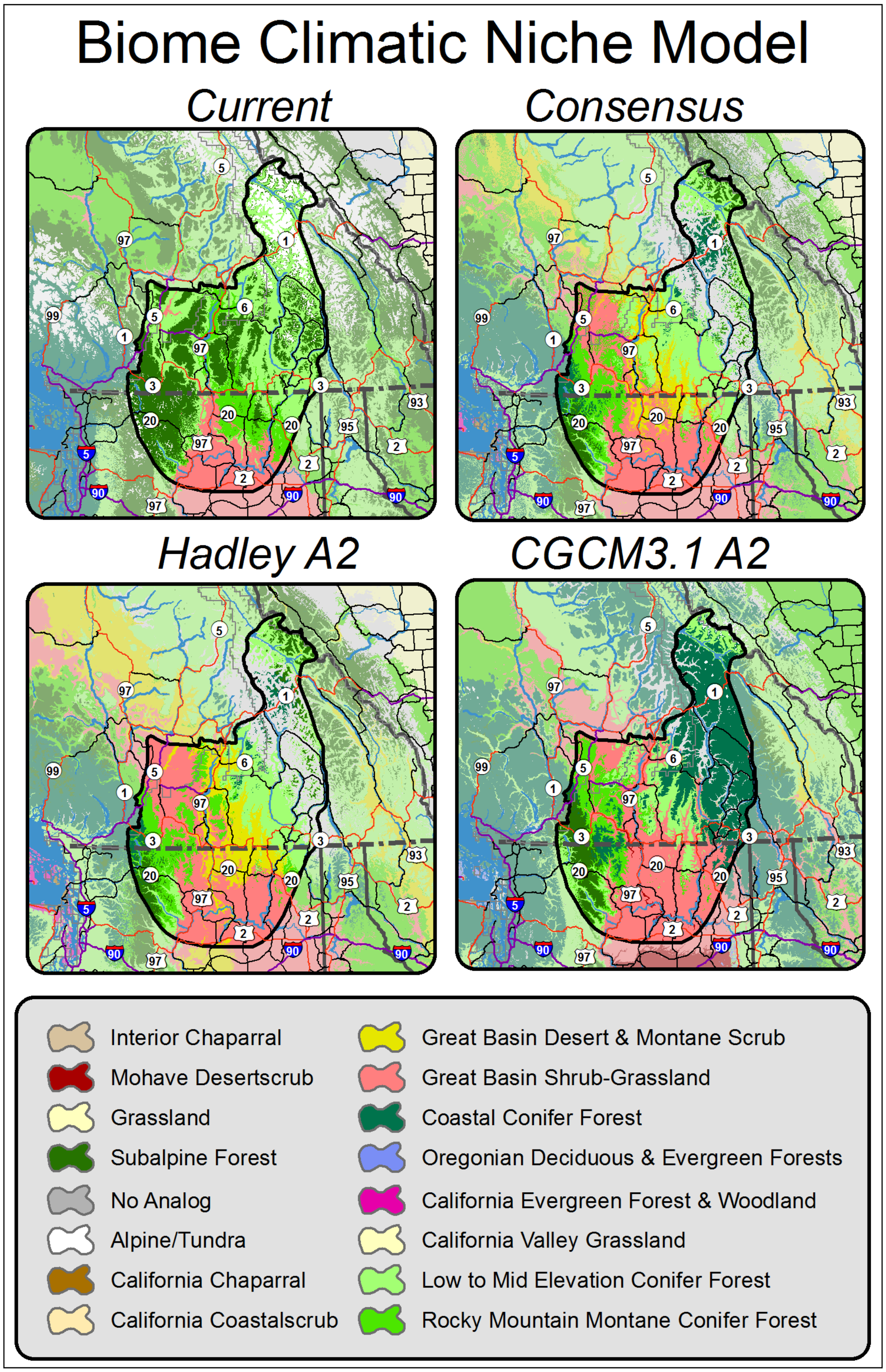
[xii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xiii] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xiv] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

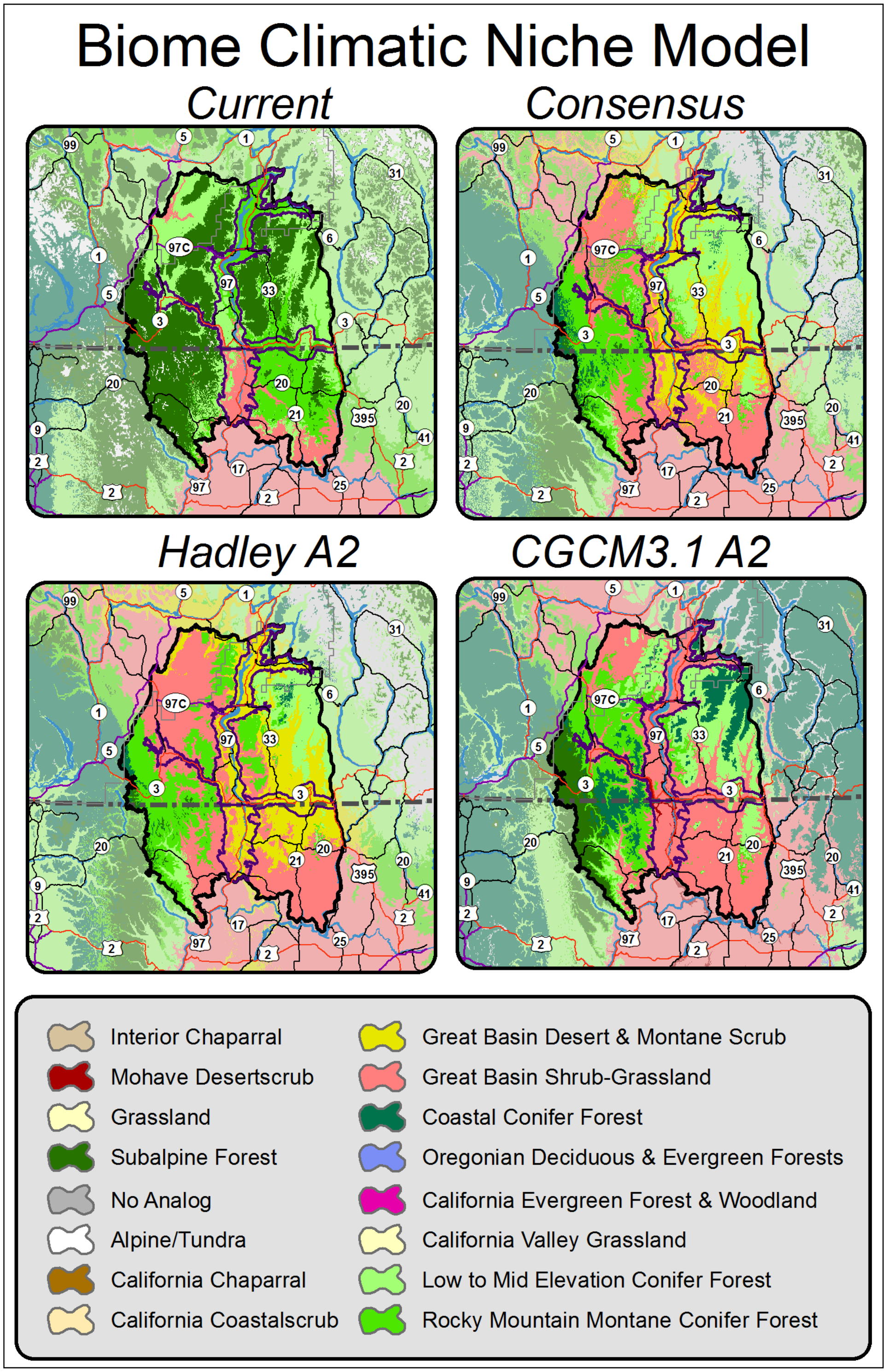
Appendix F.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



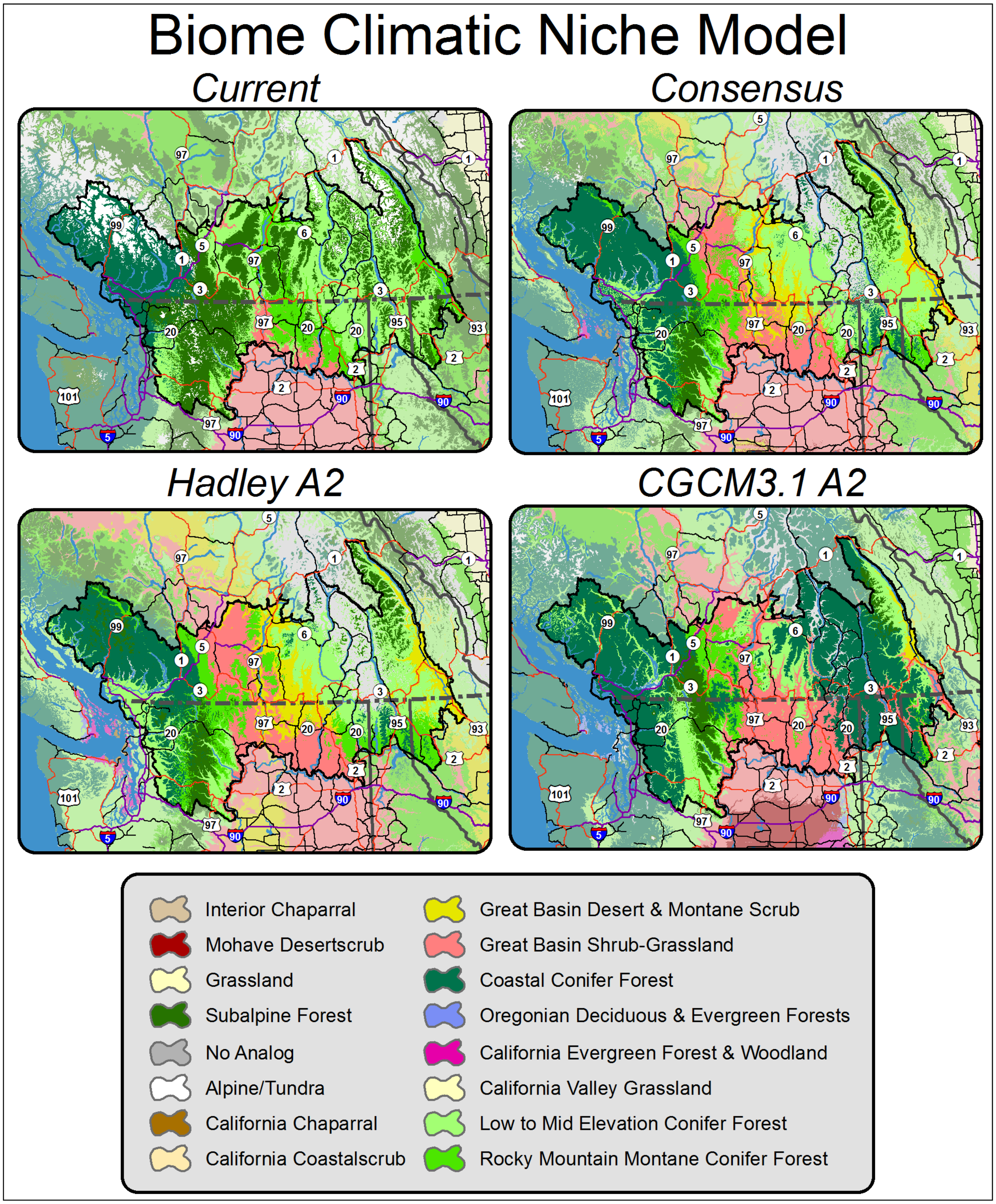
Appendix F.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



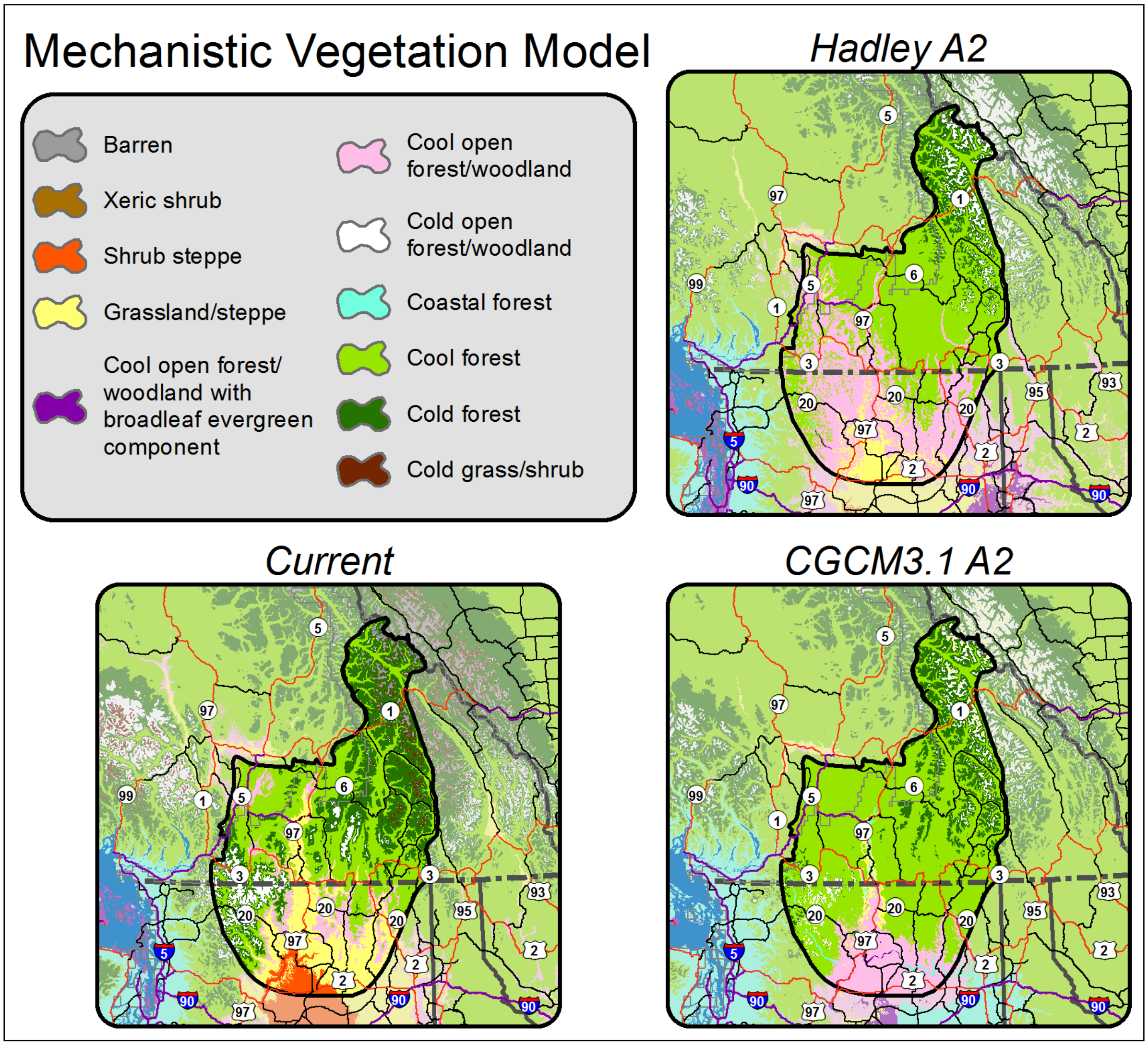
Appendix F.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



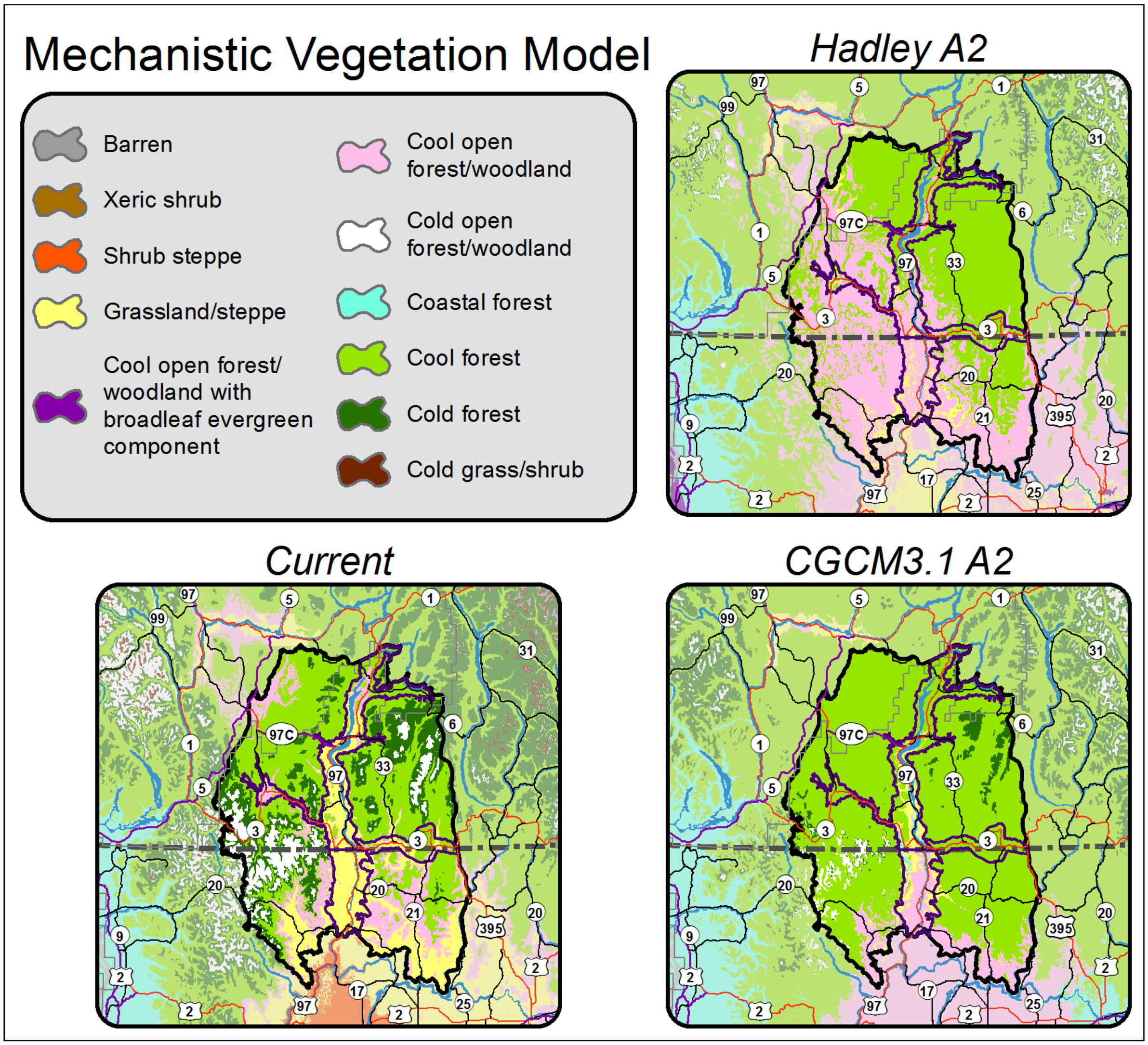
Appendix F.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



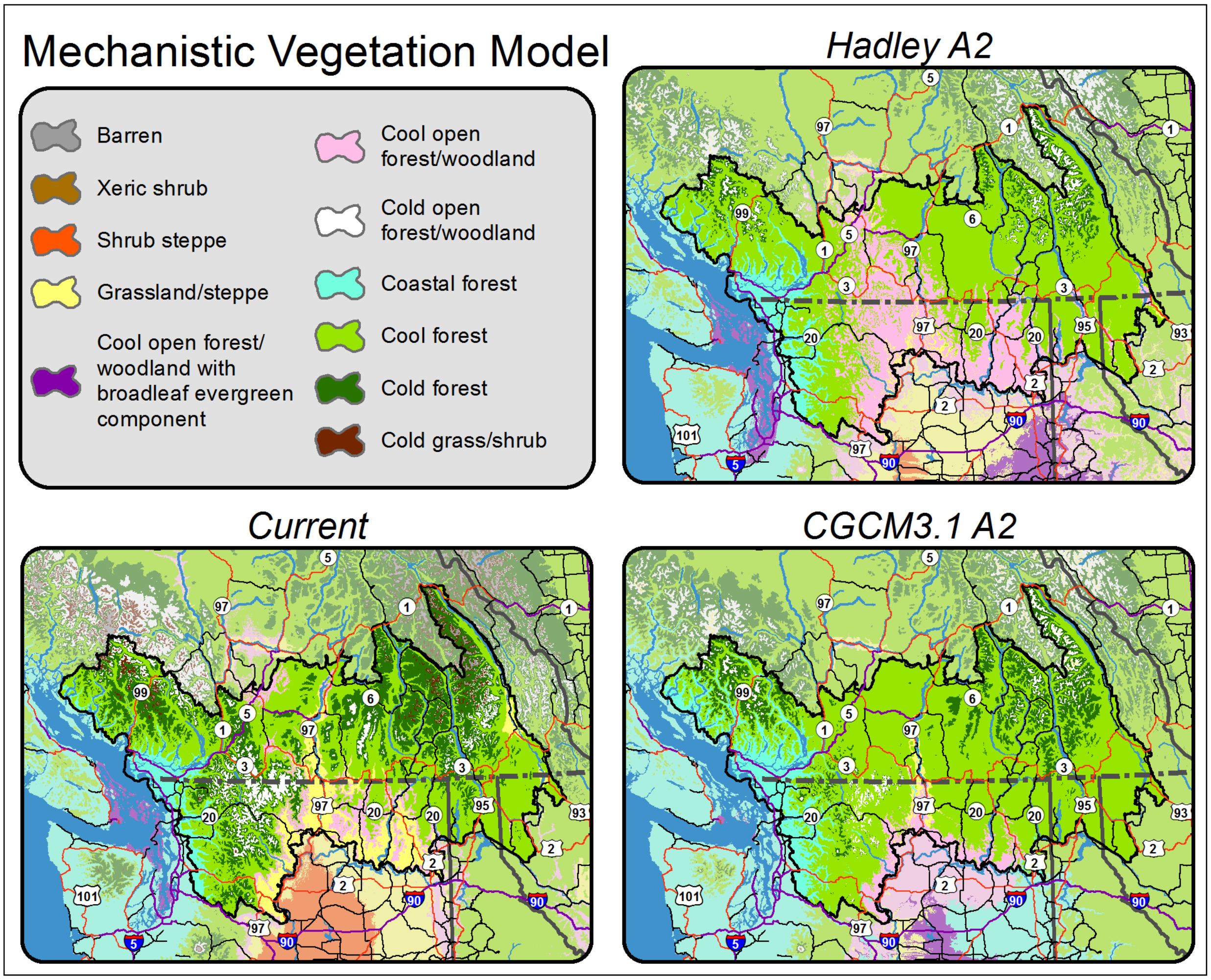
Appendix F.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix F.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix F.5. Projected Changes in Probability of Mountain Pine Beetle Survival

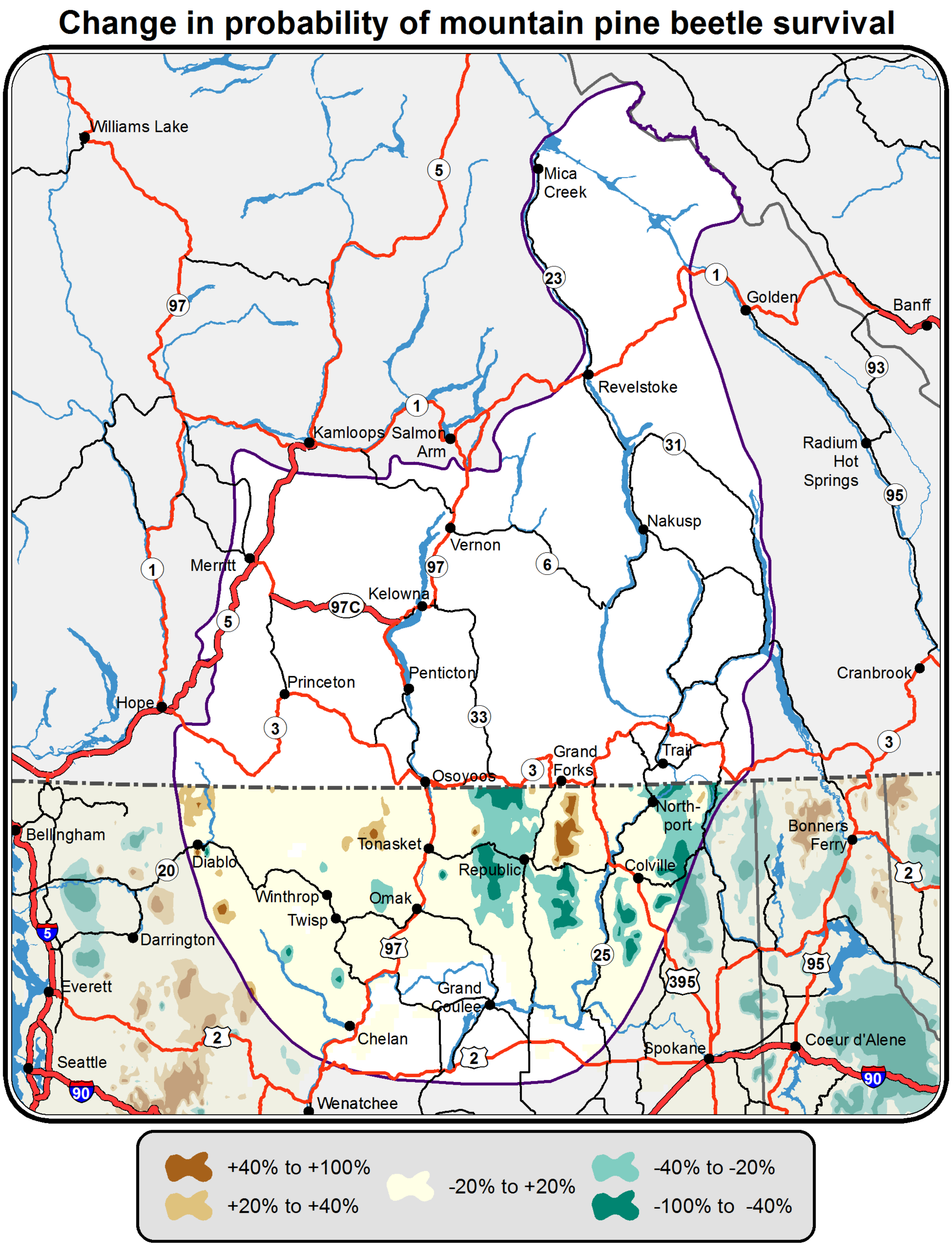
Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are projected to decrease in the future.[xv,xvi]

[xv] Mote, P.W., Snover, A.K., Capalbo, S.M., Eigenbrode, S., Glick, P., Littell, J.S., Raymondi, R., Reeder, S. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.

[xvi] Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance, spring precipitation, and seasonal heat accumulation. [xv] Projections are only available for the United States.

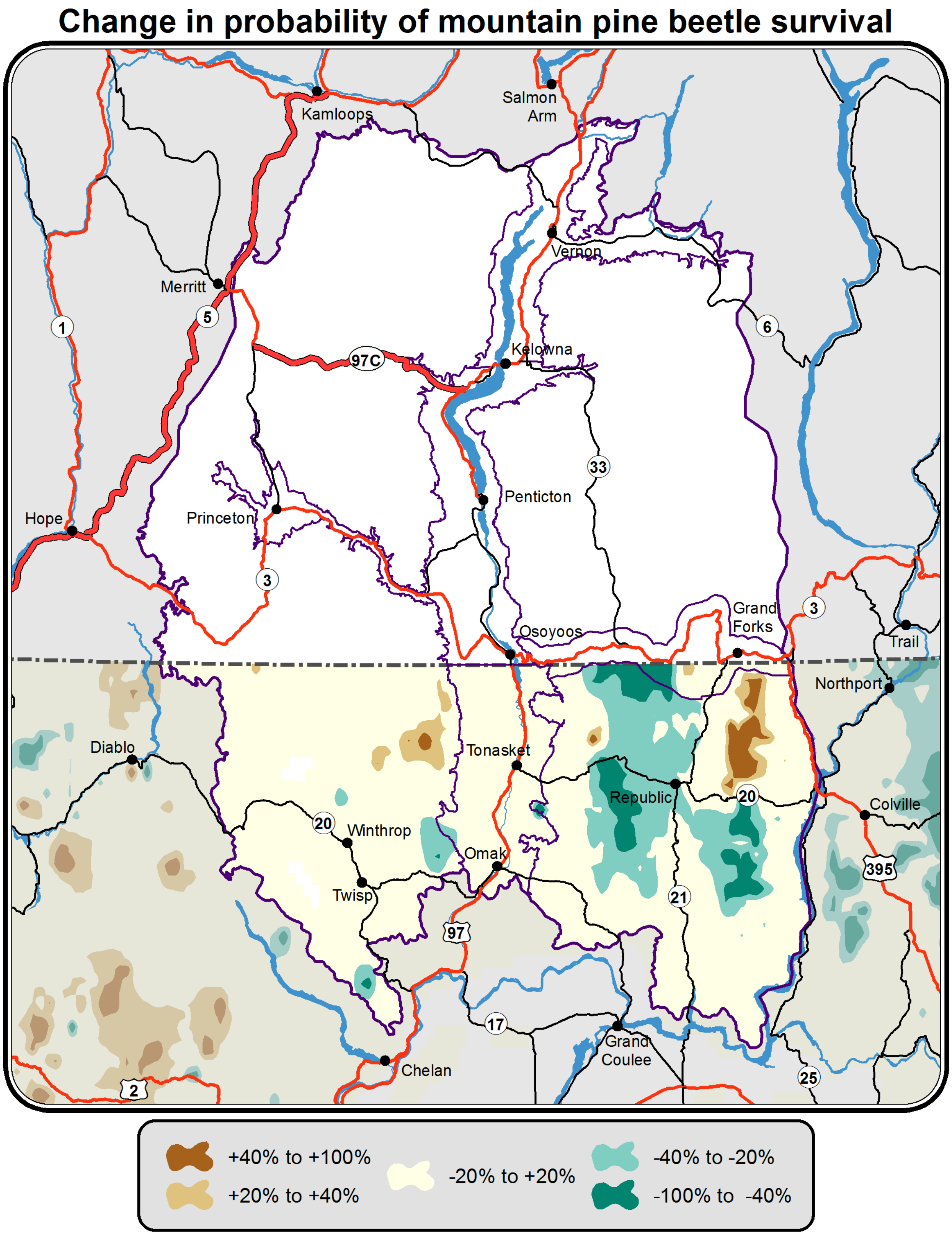
Appendix F.5. Probability of Mountain Pine Beetle Survival

i) Extent: Okanagan Nation Territory



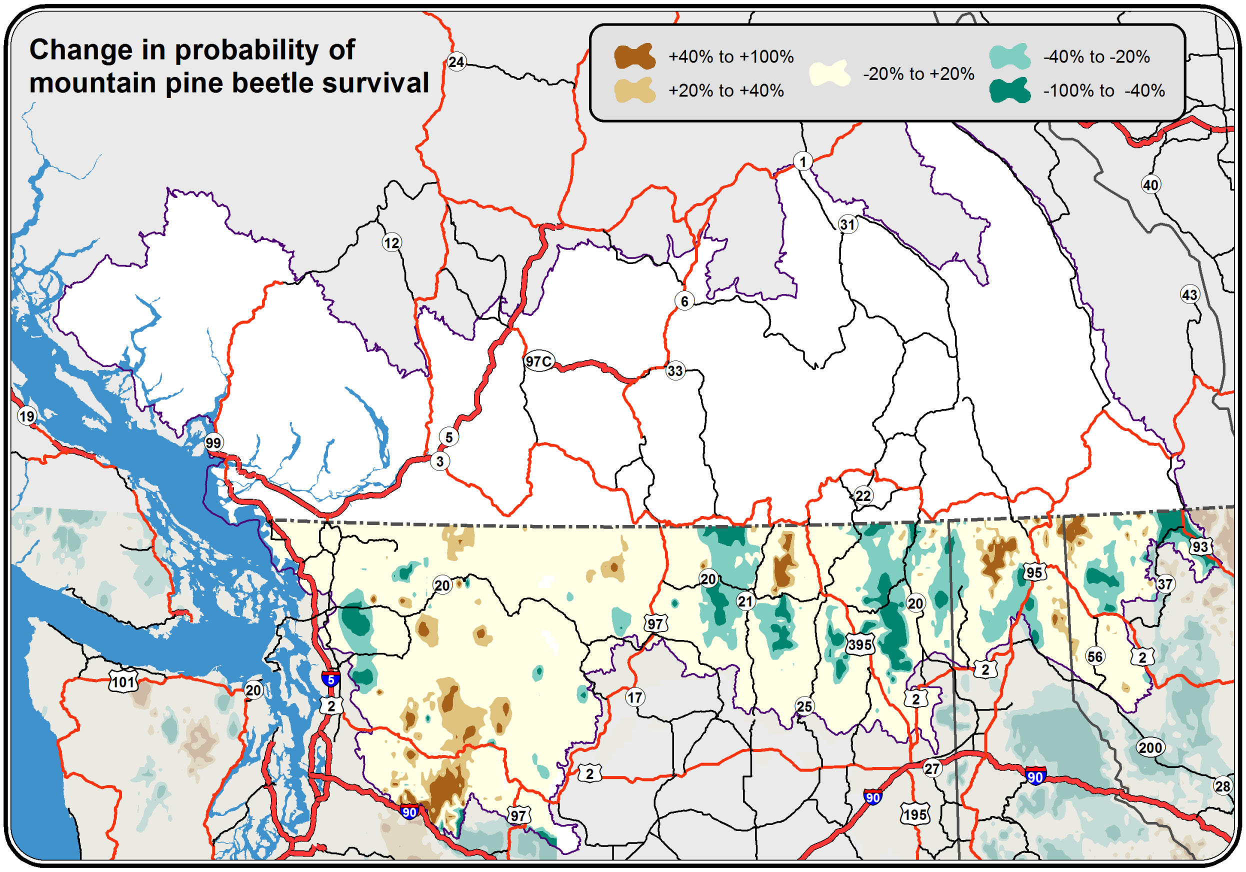
Appendix F.5. Probability of Mountain Pine Beetle Survival

ii) Extent: Okanagan-Kettle Region



Appendix F.5. Probability of Mountain Pine Beetle Survival

iii) Extent: Washington-British Columbia Transboundary Region



Appendix F.6. Projected Changes for Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on American marten connectivity.[xvii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[8] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Late Spring (May 1st) Snowpack.** This map shows the projected change, in percent, in snow water equivalent (SWE) on May 1st. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

c) **Length of Snow Season.** This map shows the projected change in the length of the snow season, defined as the number of days between the first and last days of the season with at least 10% of annual maximum snow water equivalent. Projected changes in snow season length are depicted by the yellow to red shading.

d) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

e) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xviii] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

f) **Number of Heavy Precipitation Days.** This map shows projected change, in percent, in the number of heavy precipitation days, defined as the annual count of days with at least 10 mm of precipitation. Projected changes in heavy precipitation days are depicted by the yellow to green shading.

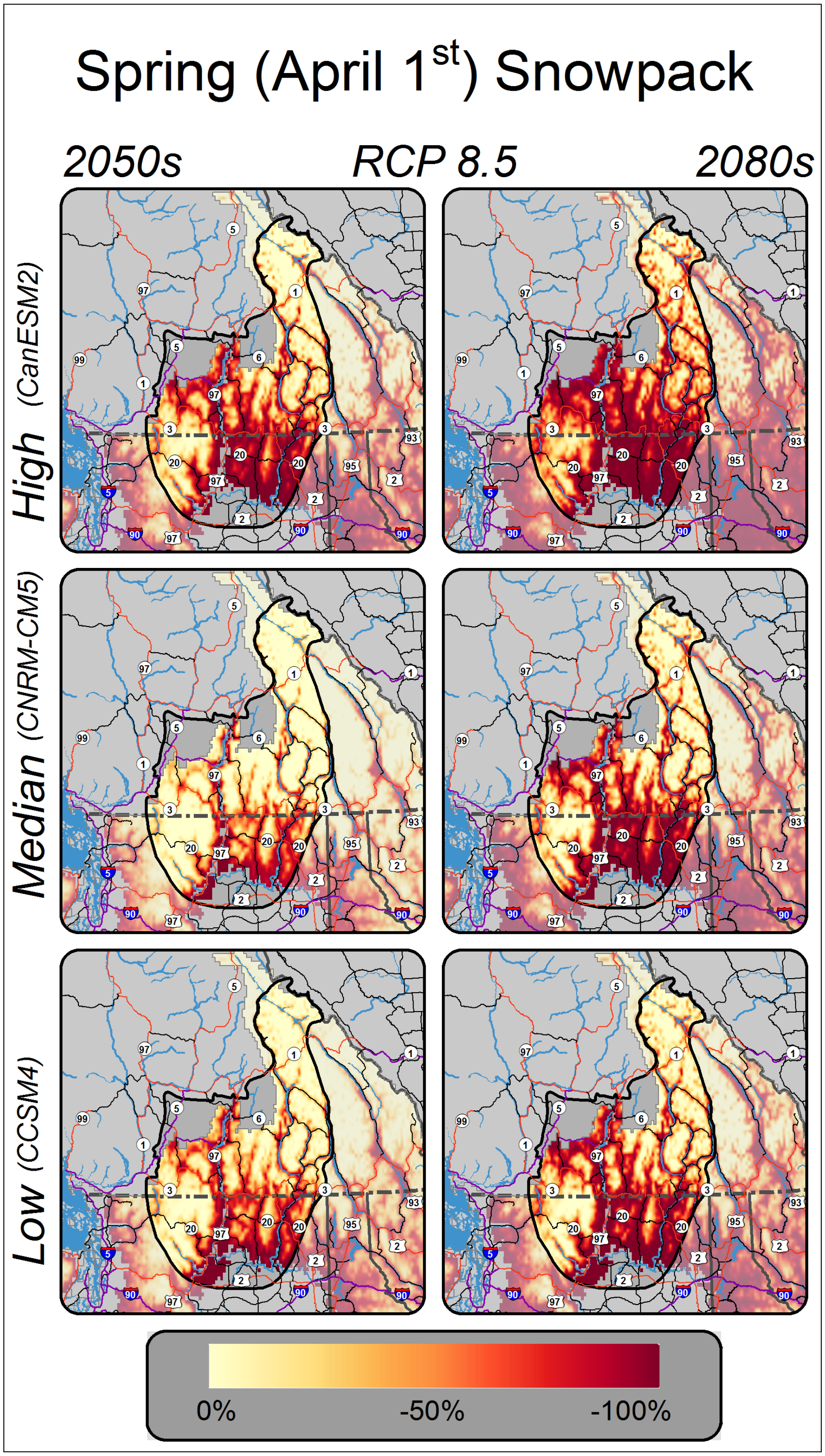
[xvii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

[xviii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

g) **Average Precipitation Intensity.** This map shows projected change, in percent, in the average precipitation intensity. Projected changes in precipitation intensity are depicted by the yellow to green shading.

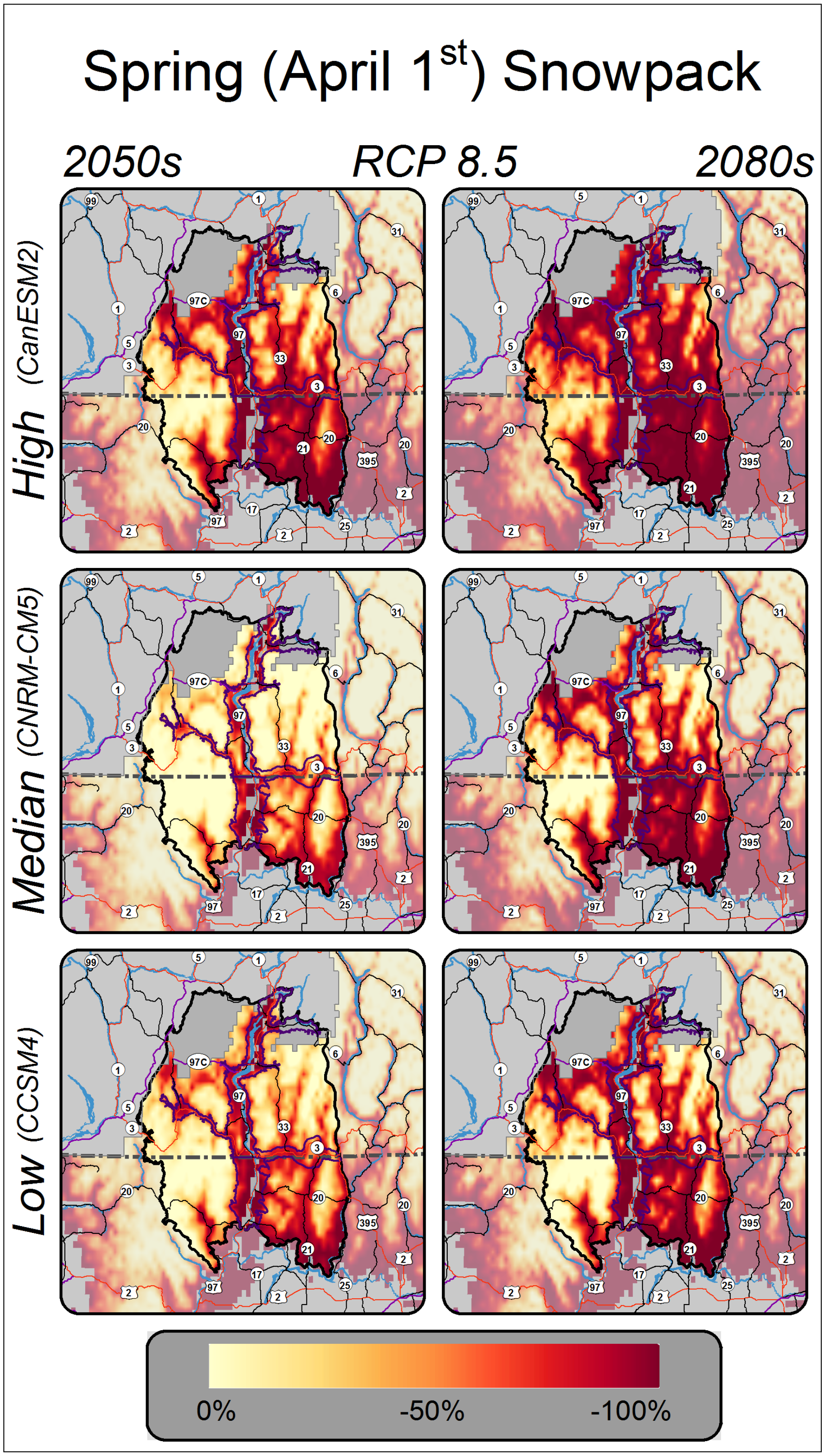
Appendix F.6a. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



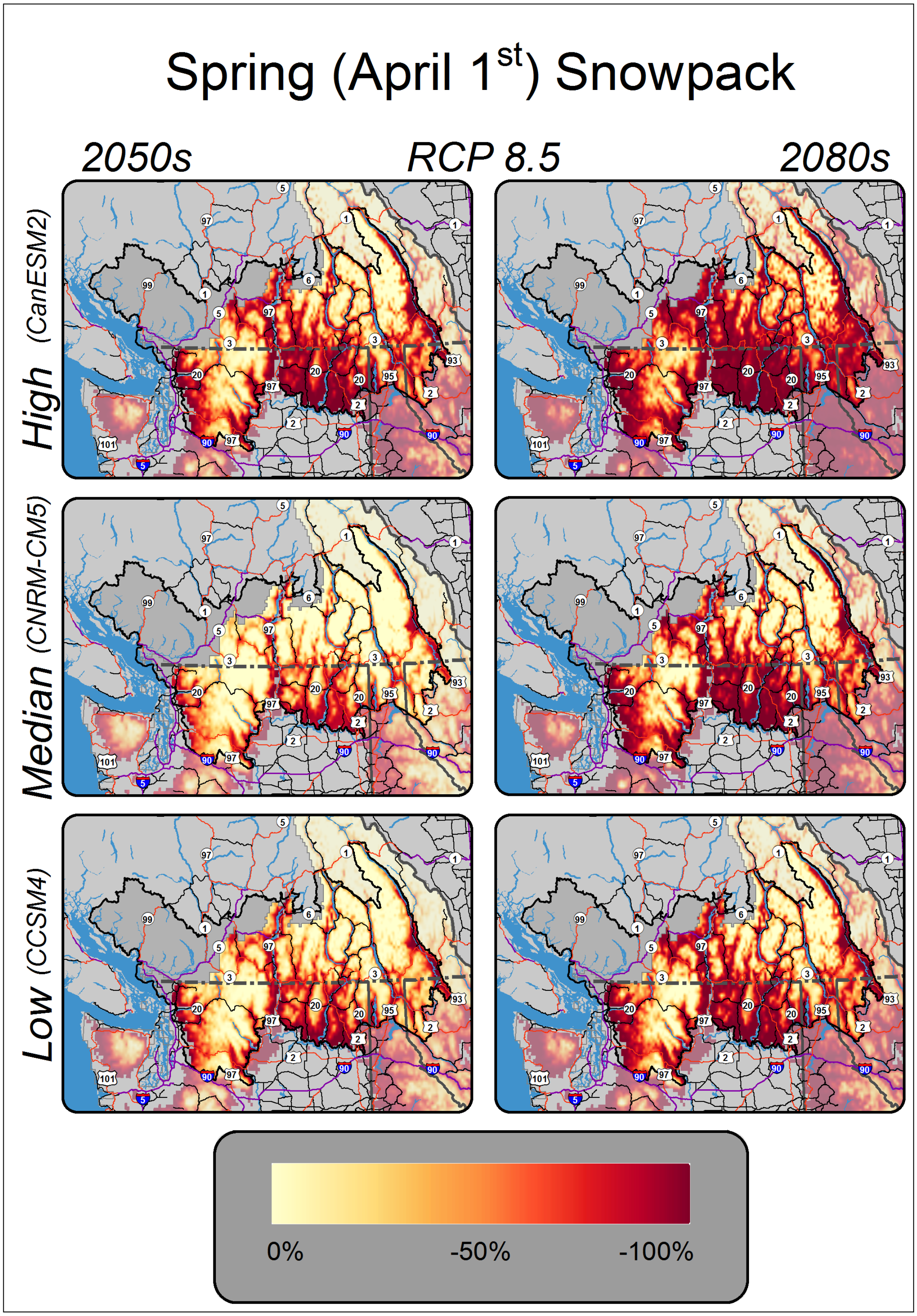
Appendix F.6a. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



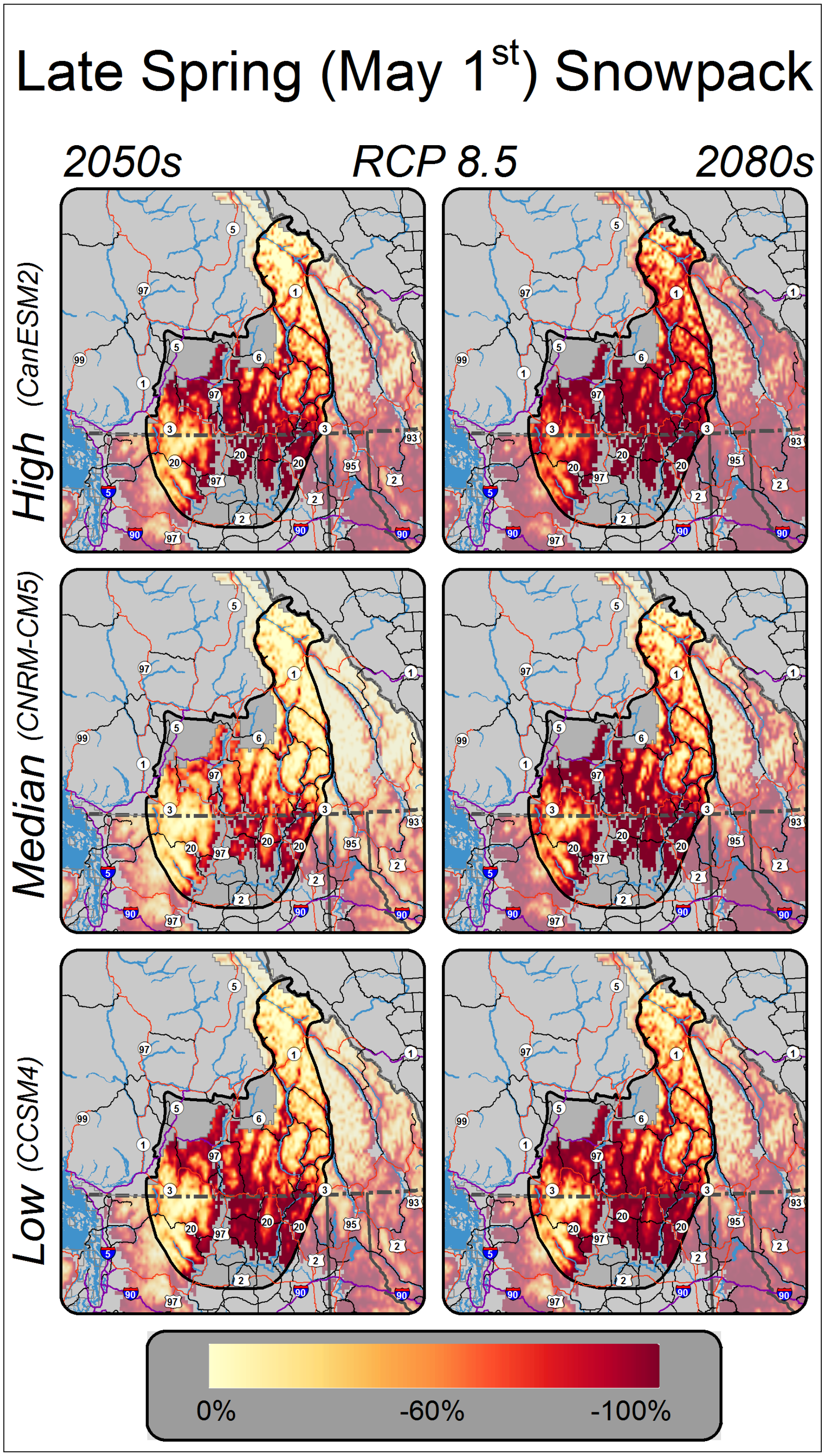
Appendix F.6a. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



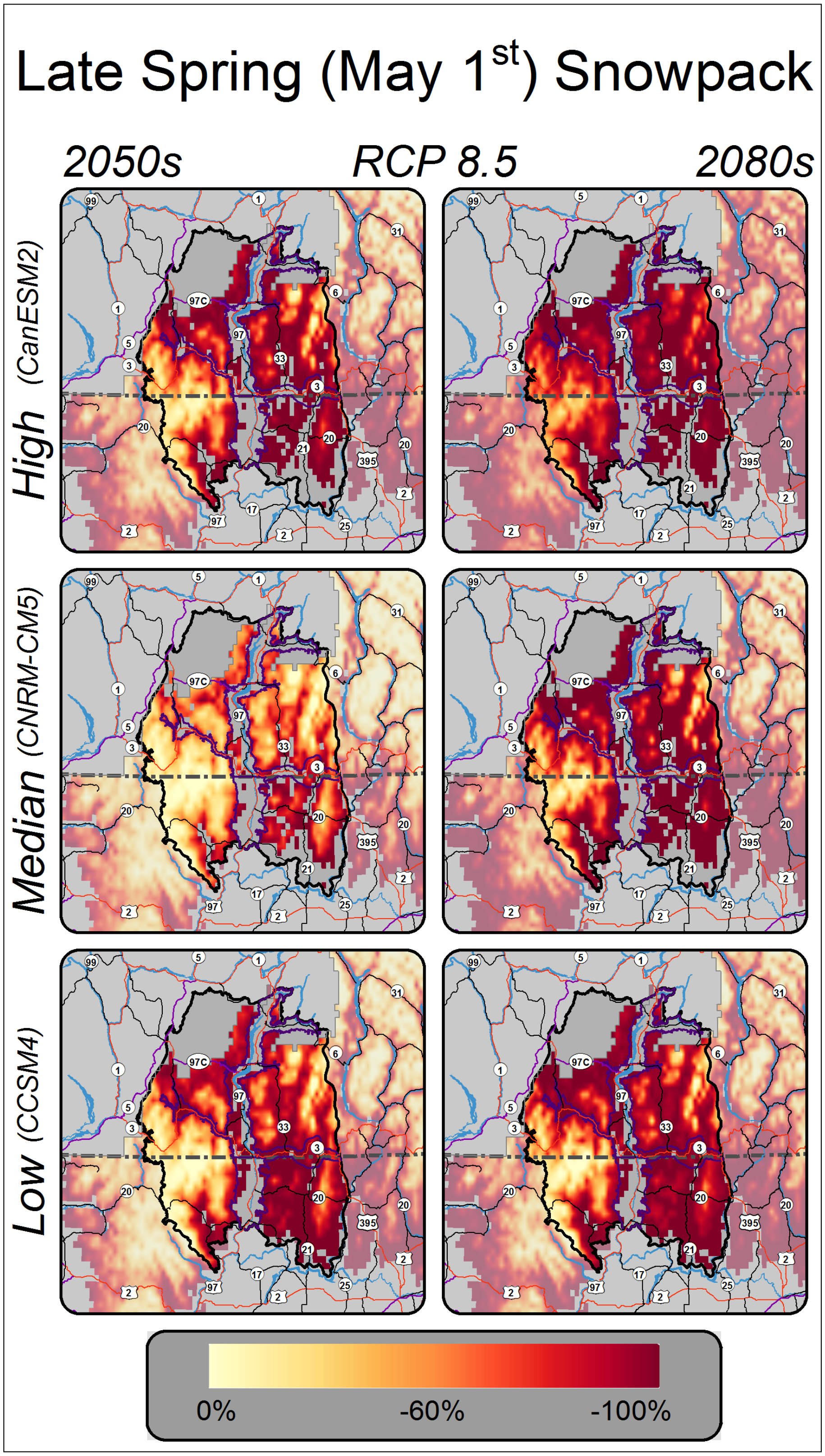
Appendix F.6b. Late Spring (May 1st) Snowpack

i) Extent: Okanagan Nation Territory



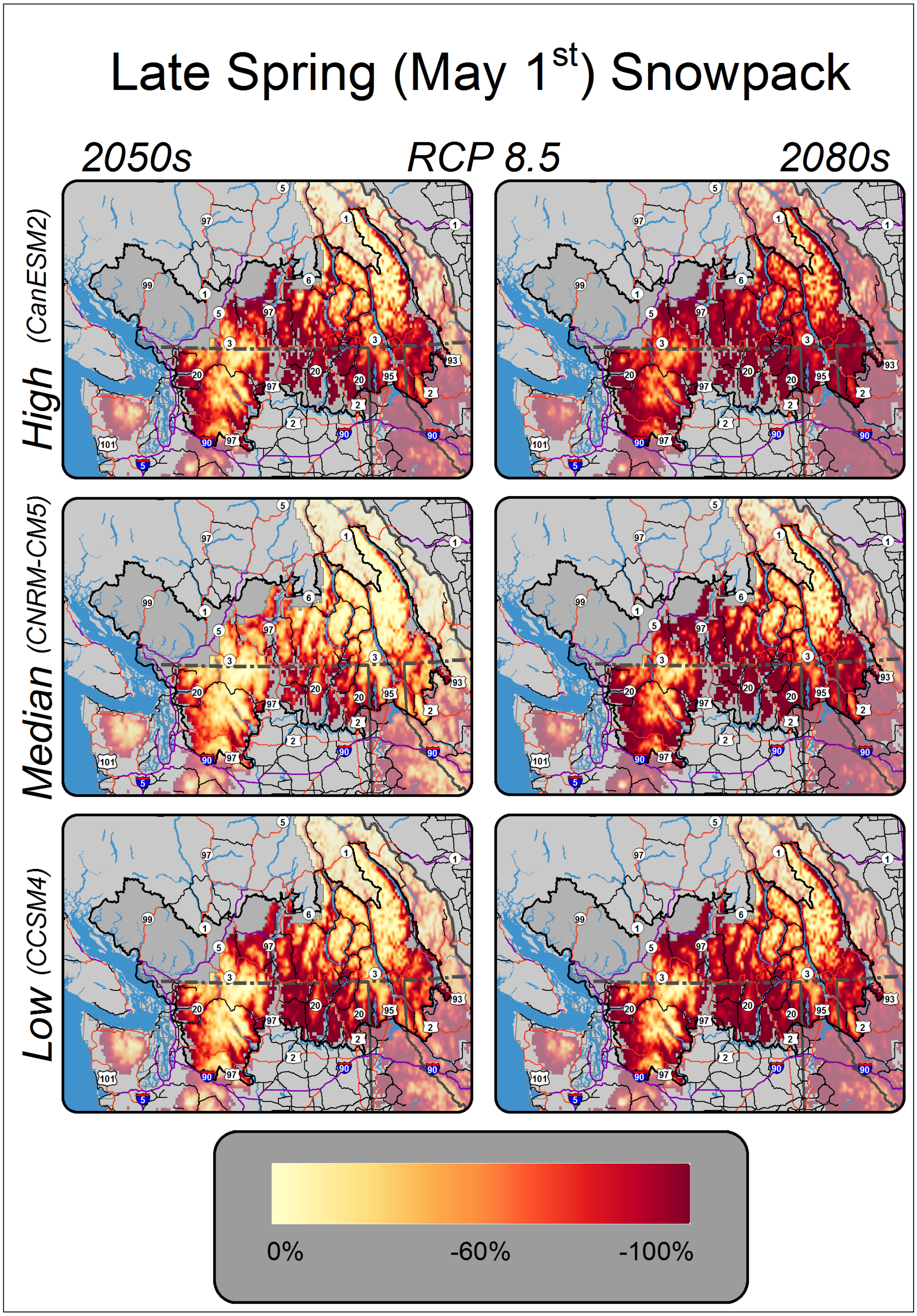
Appendix F.6b. Late Spring (May 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



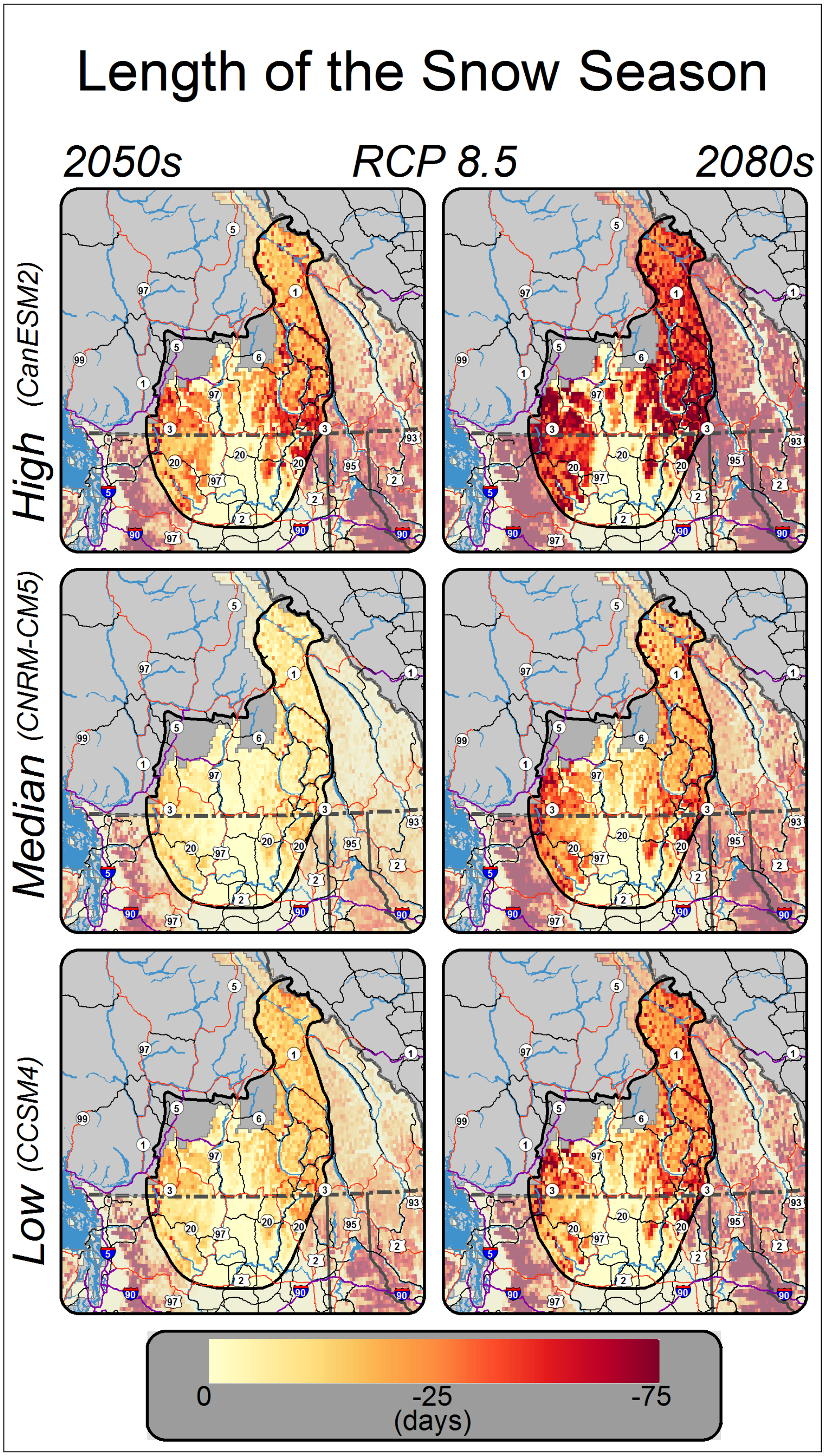
Appendix F.6b. Late Spring (May 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



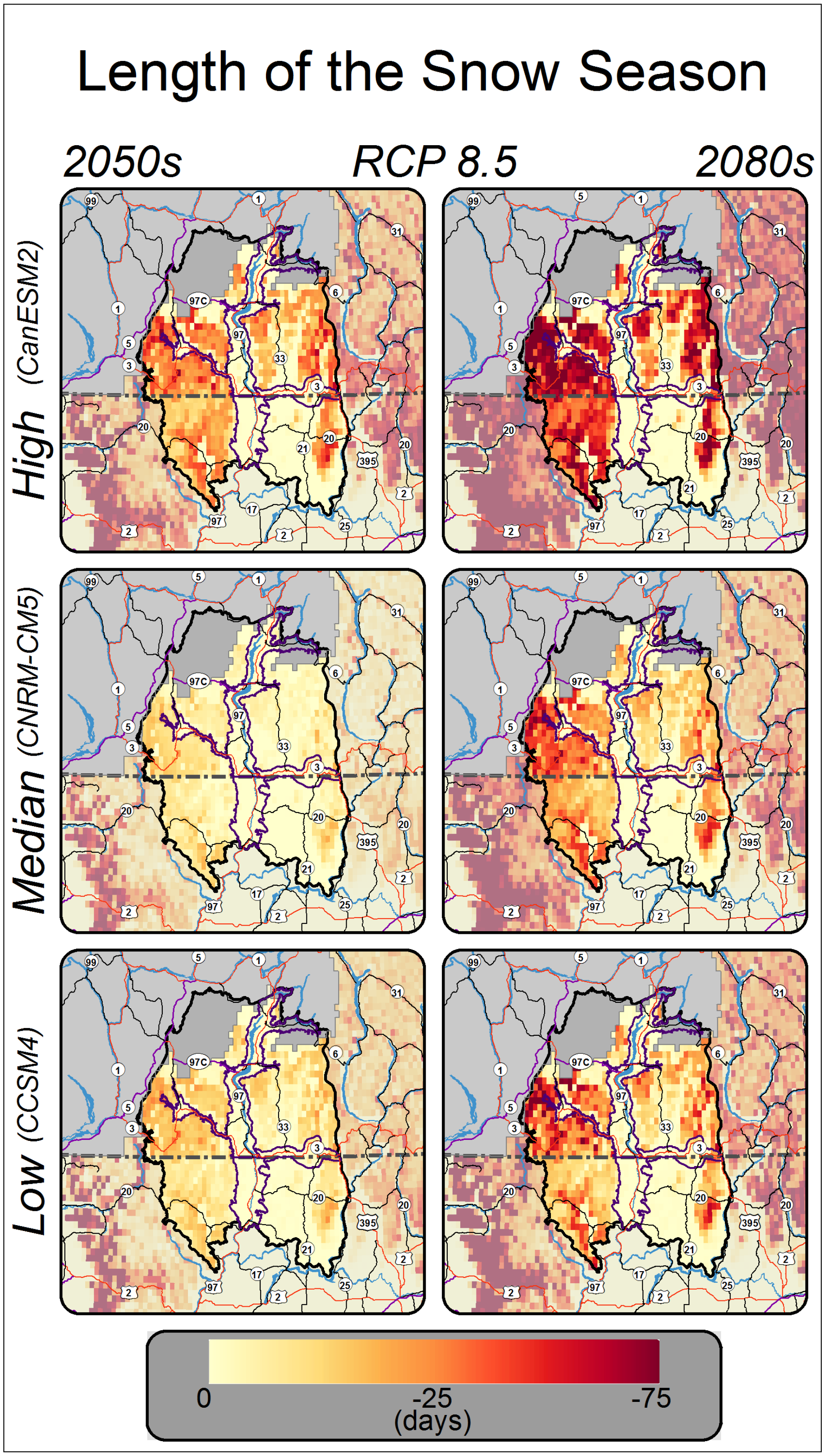
Appendix F.6c. Length of the Snow Season

i) Extent: Okanagan Nation Territory



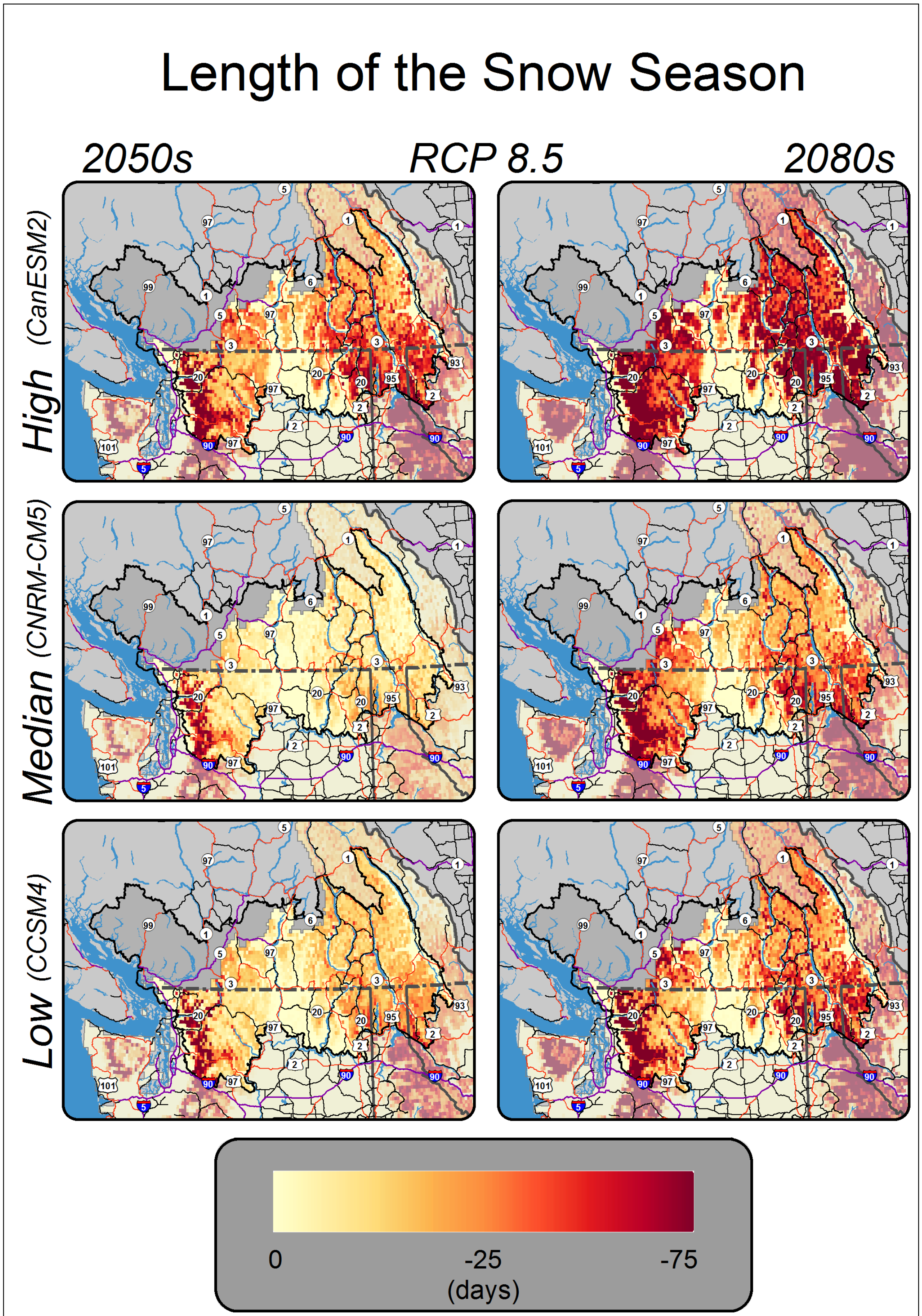
Appendix F.6c. Length of the Snow Season

ii) Extent: Okanagan-Kettle Region



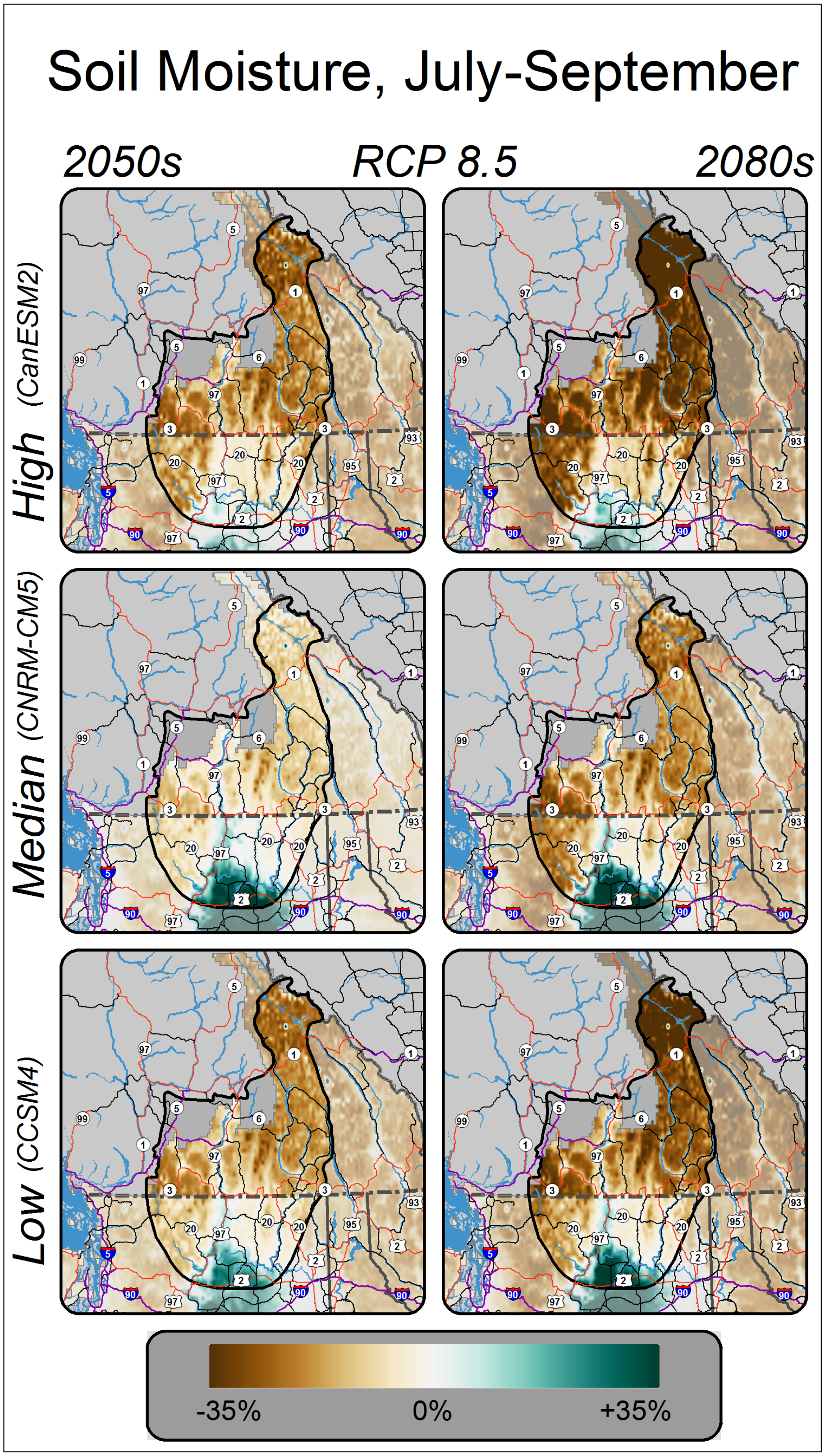
Appendix F.6c. Length of the Snow Season

iii) Extent: Washington-British Columbia Transboundary Region



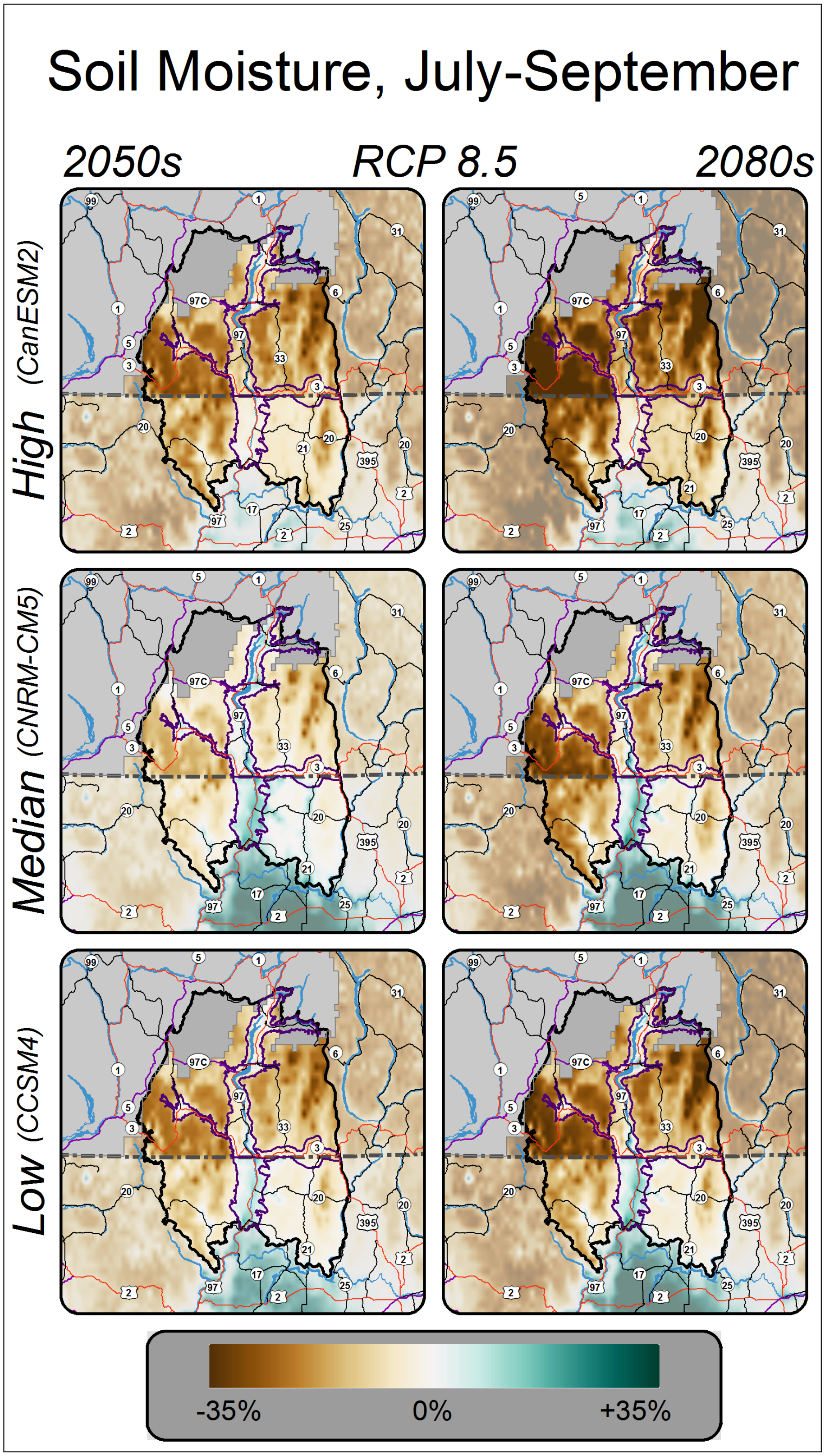
Appendix F.6d. Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



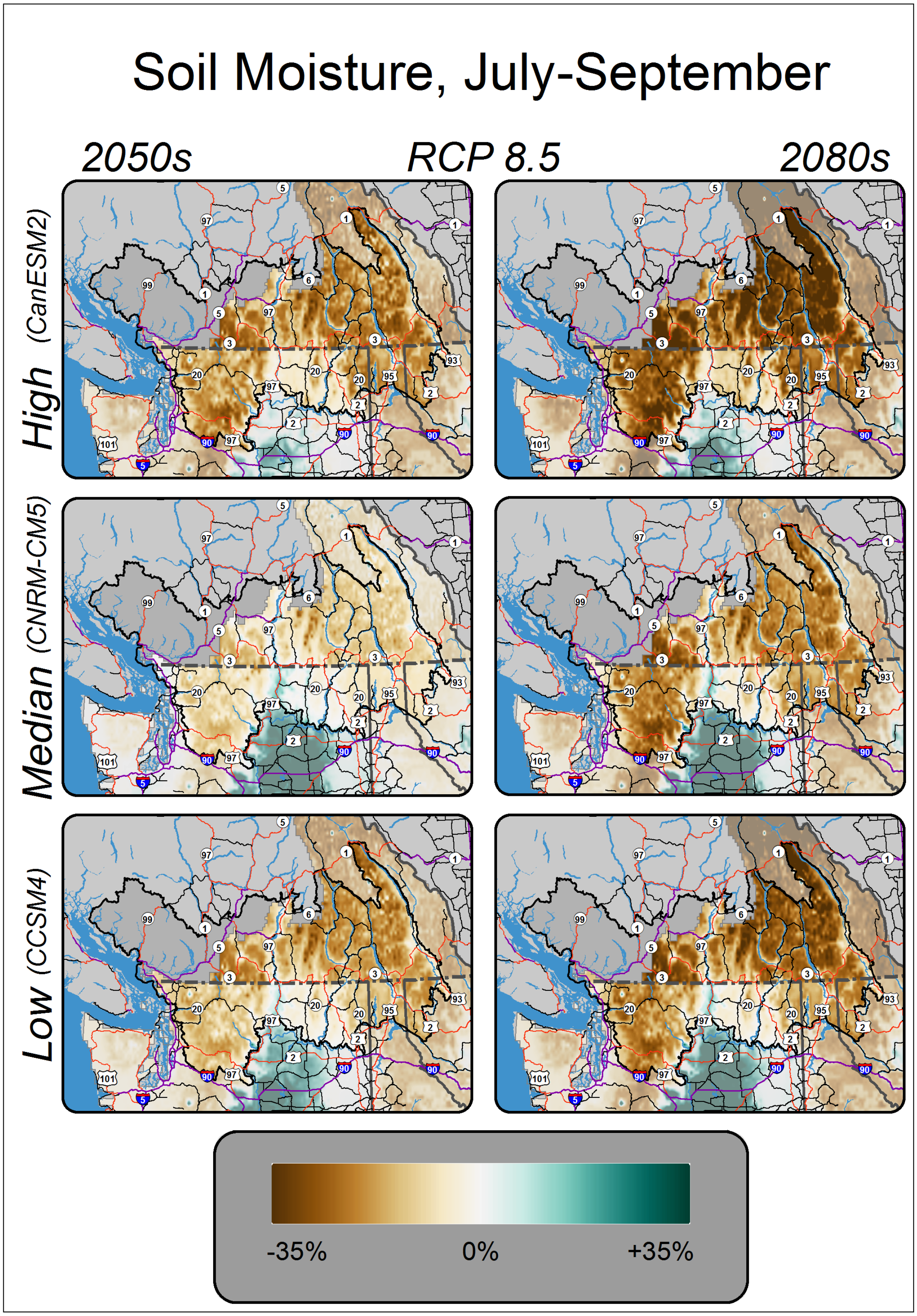
Appendix F.6d. Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



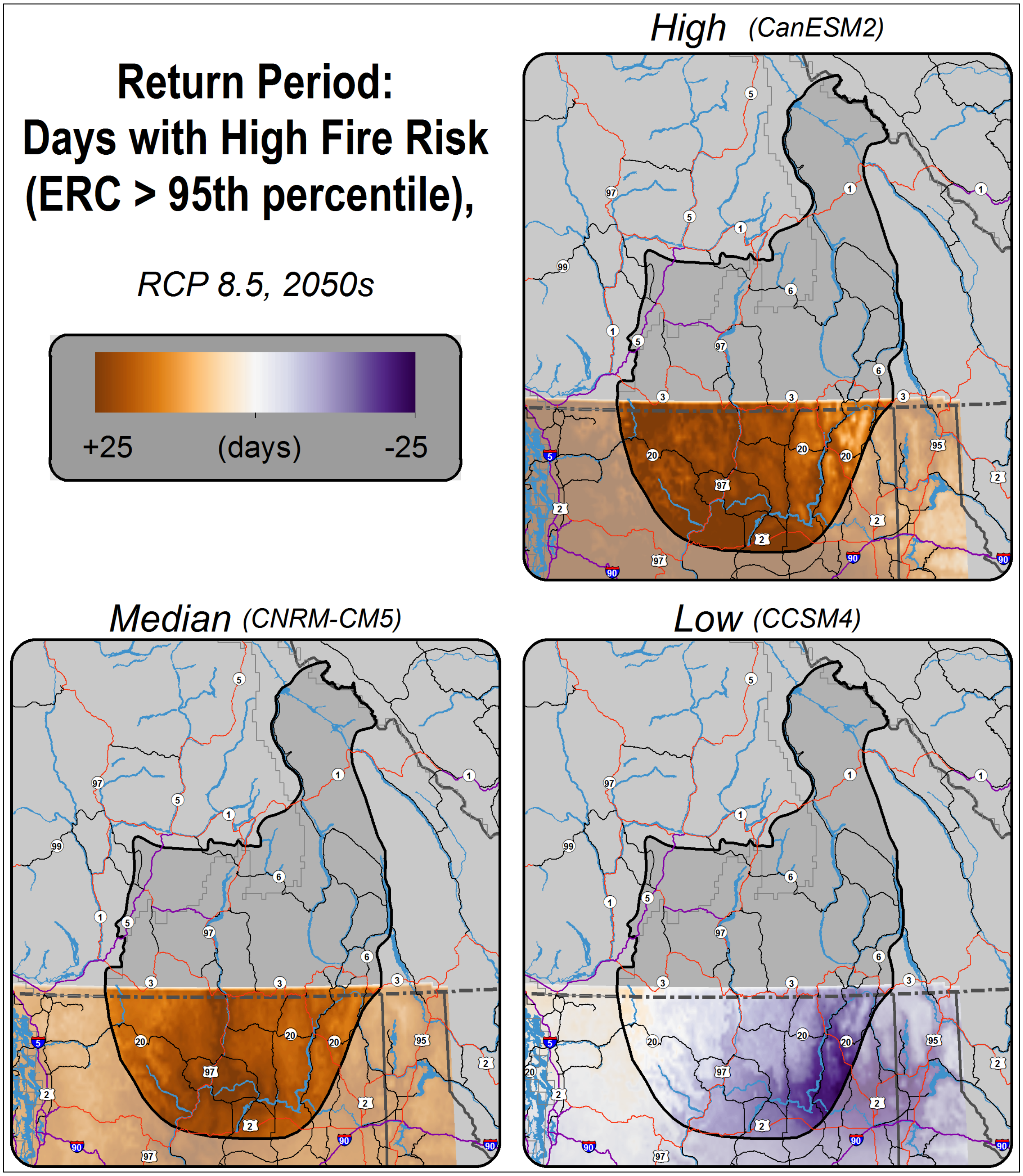
Appendix F.6d. Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region



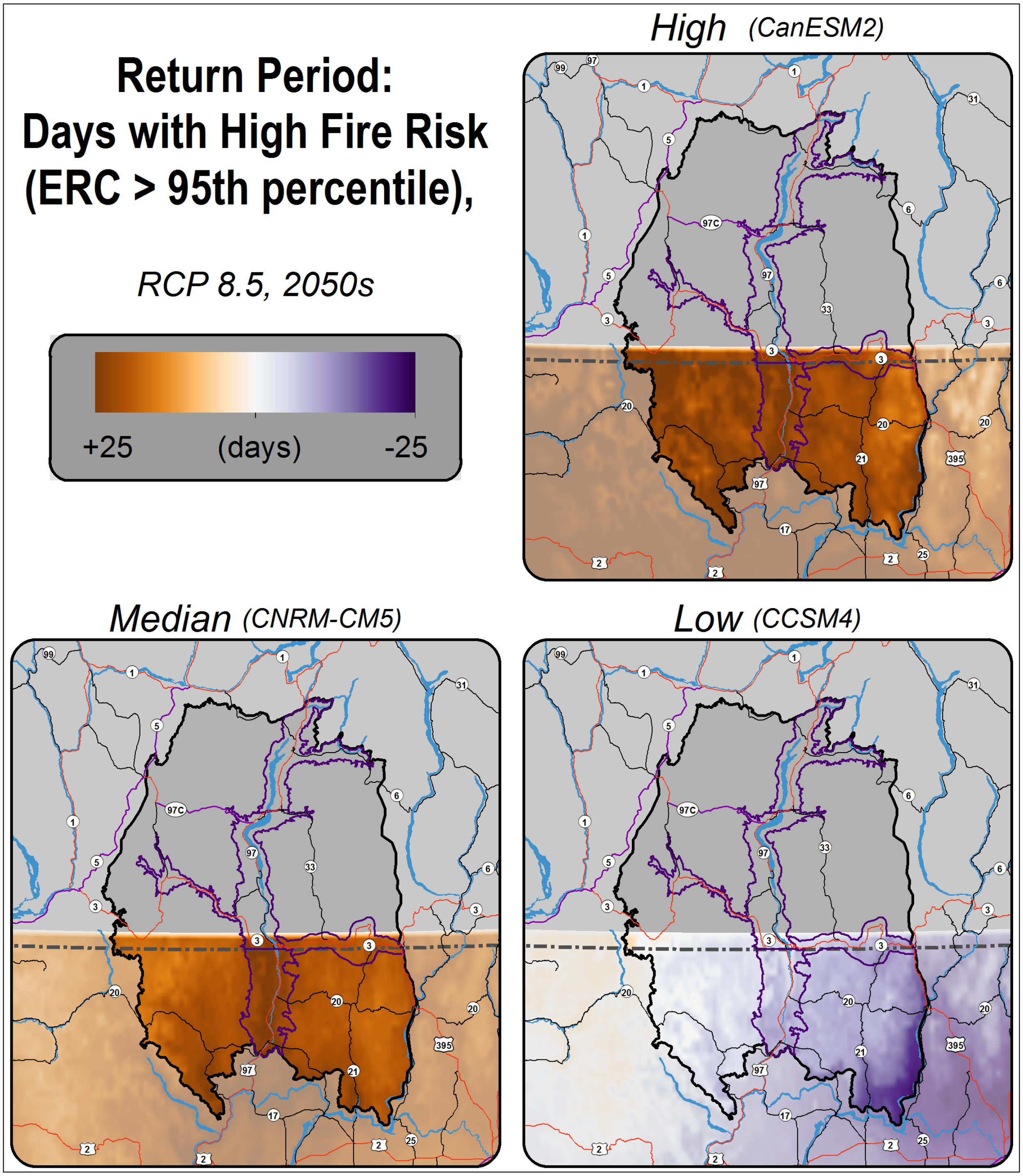
Appendix F.6e. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



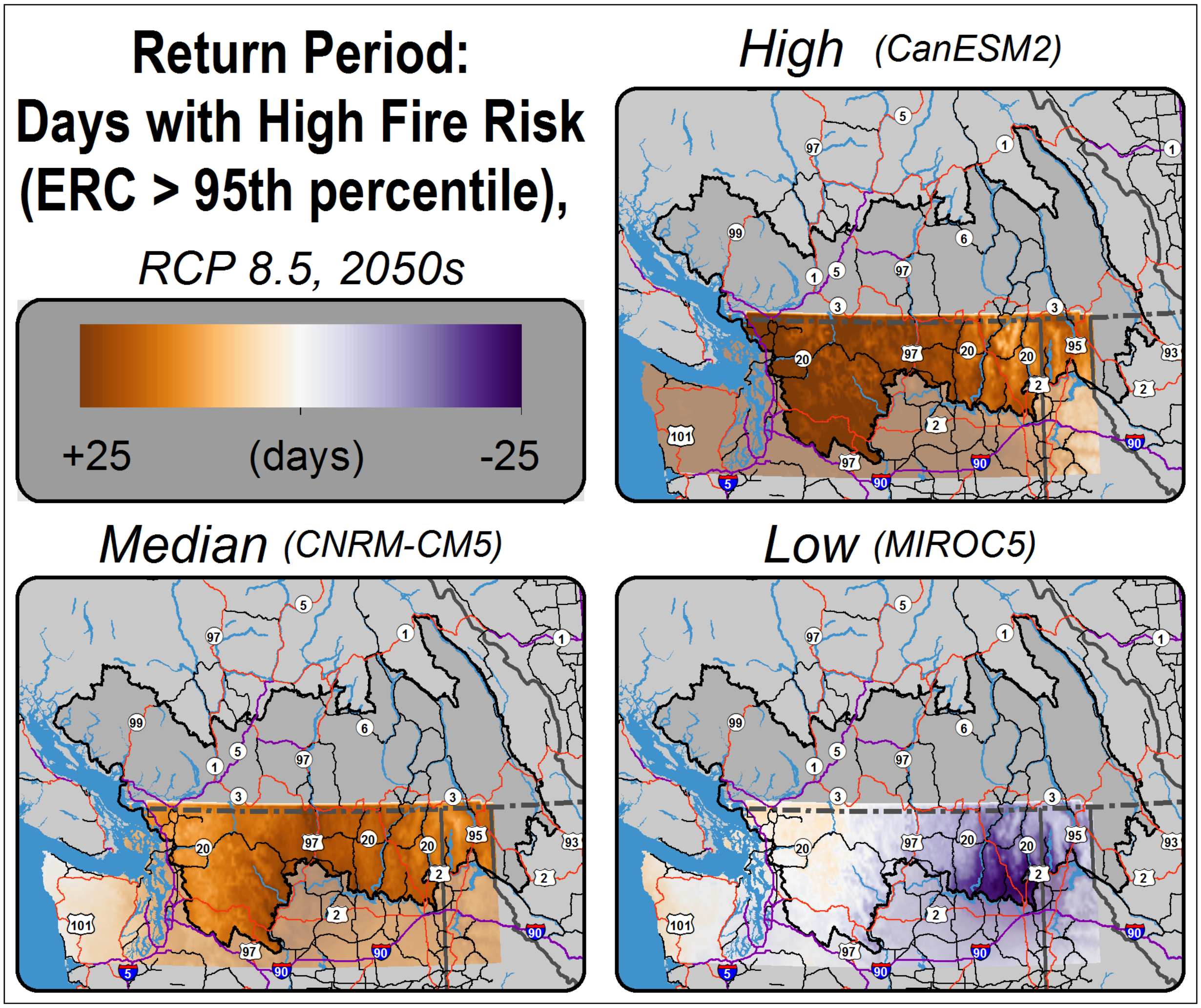
Appendix F.6e. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



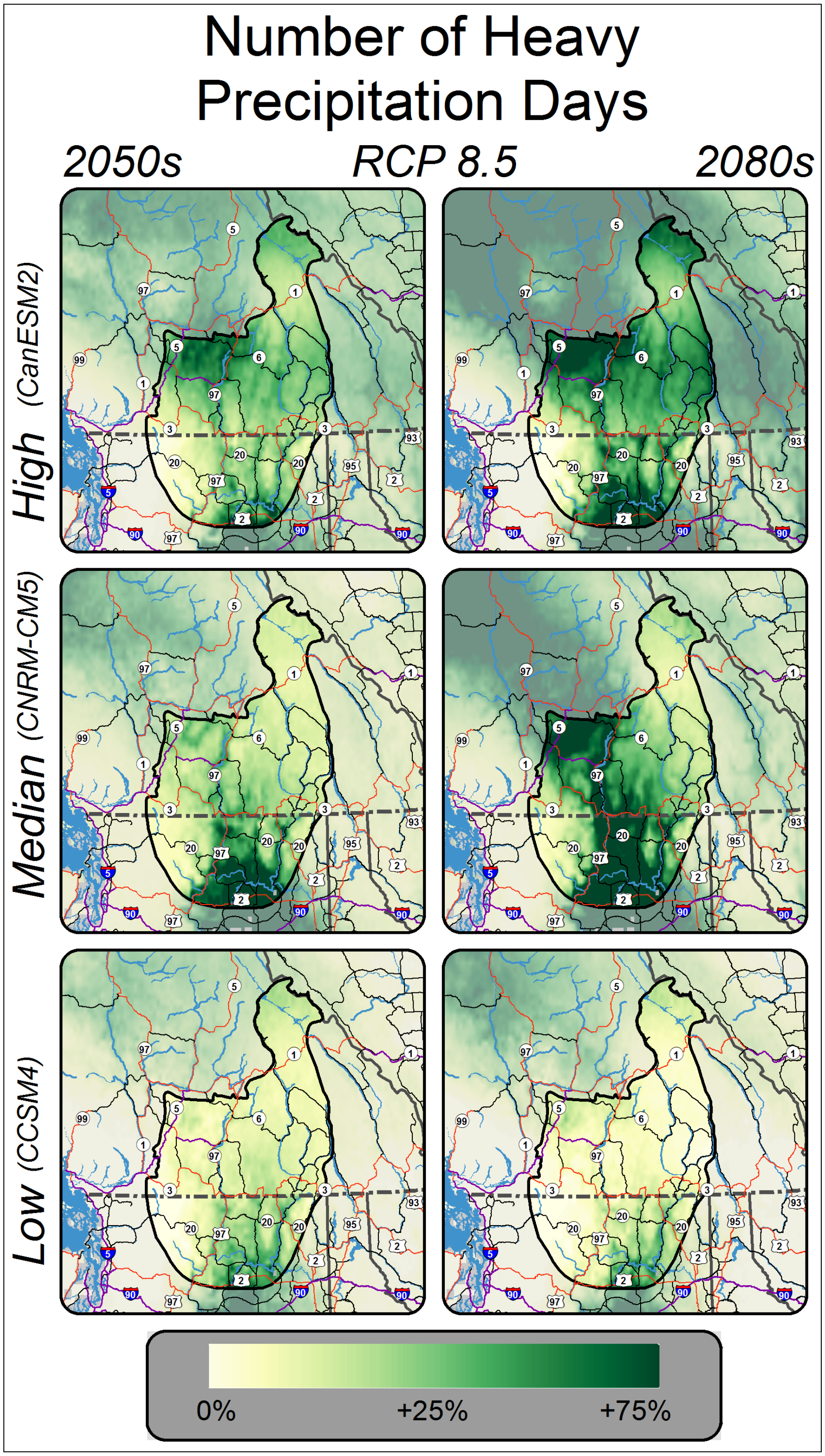
Appendix F.6e. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region



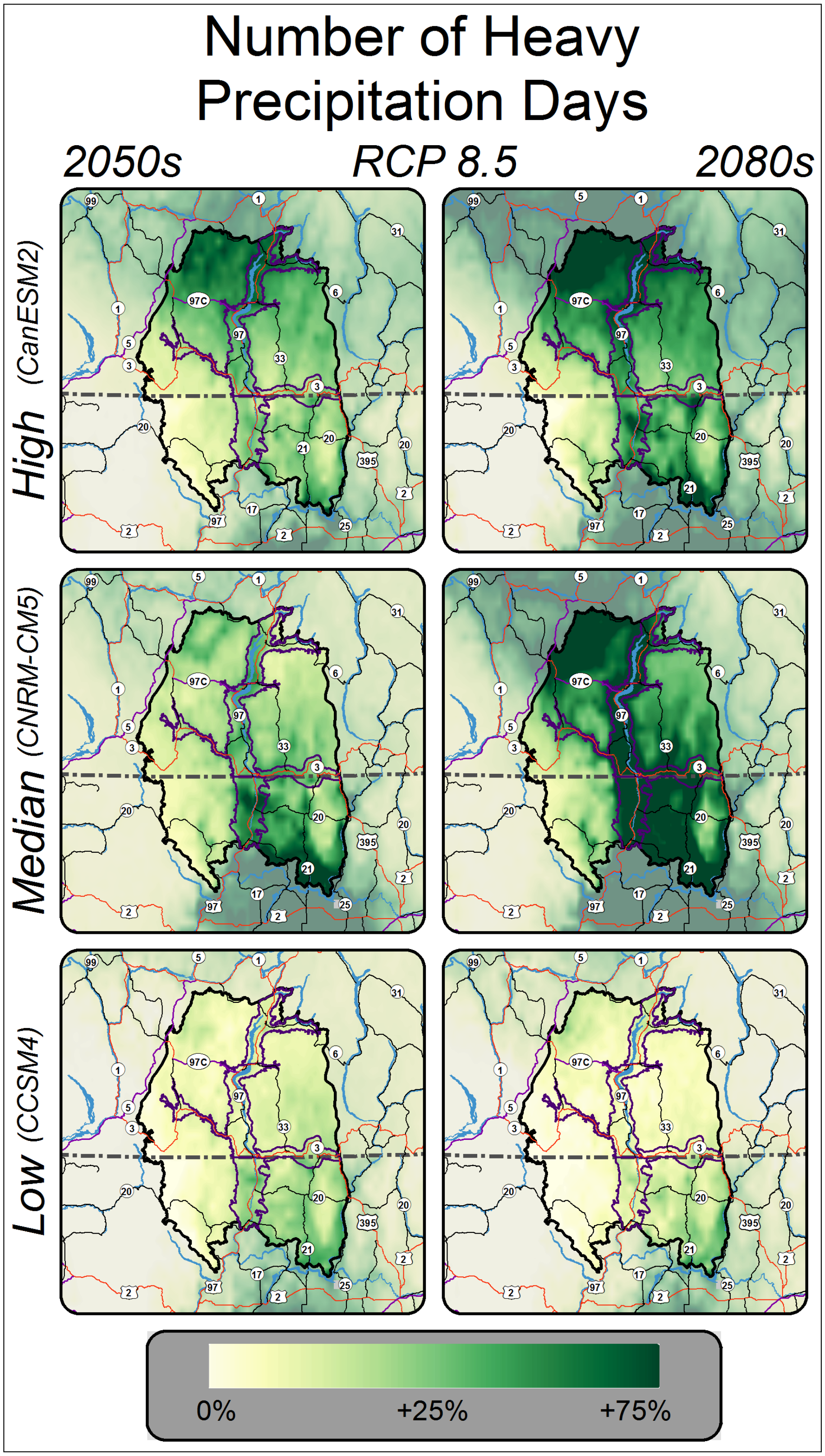
Appendix F.6f. Number of Heavy Precipitation Days

i) Extent: Okanagan Nation Territory



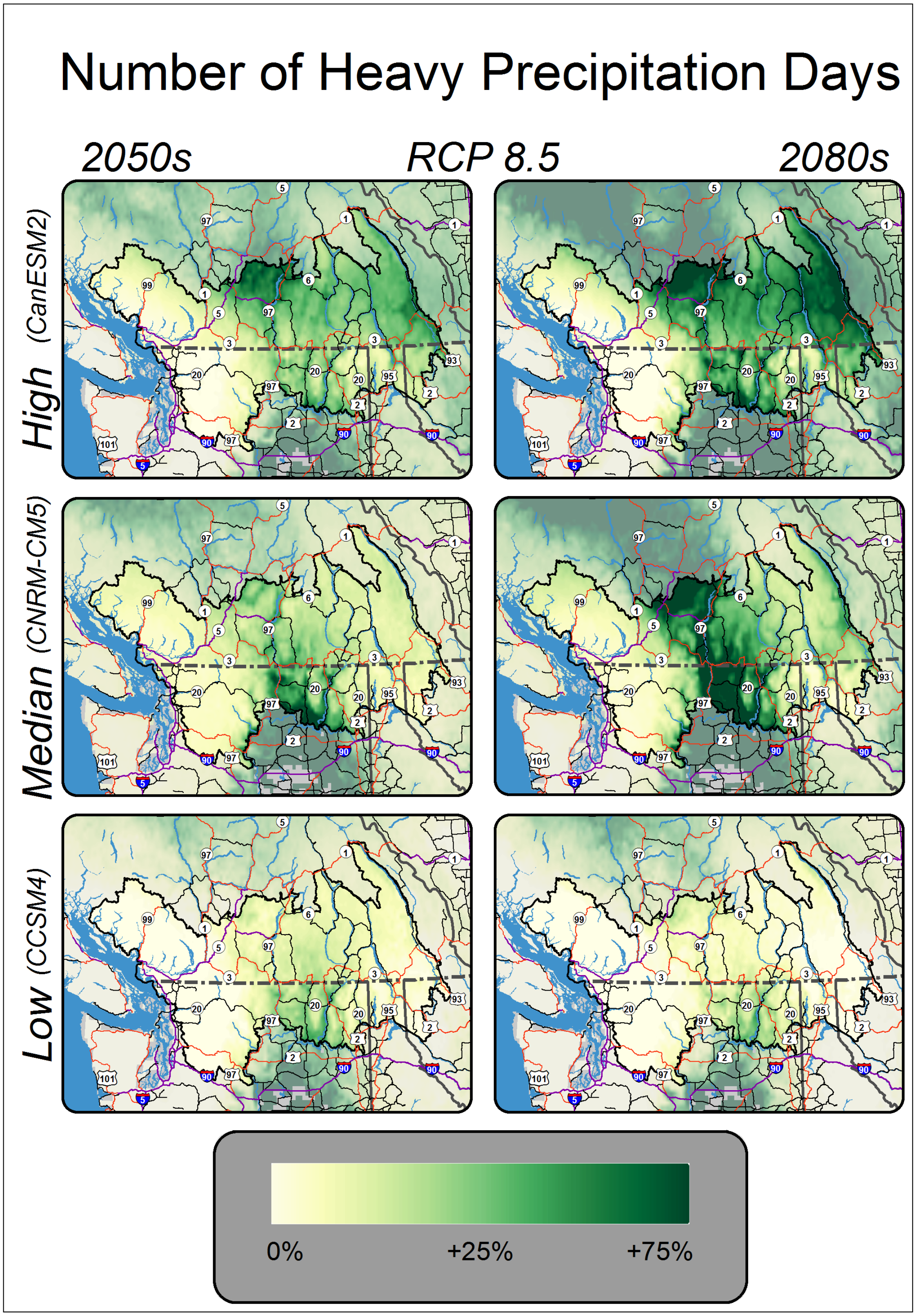
Appendix F.6f. Number of Heavy Precipitation Days

ii) Extent: Okanagan-Kettle Region



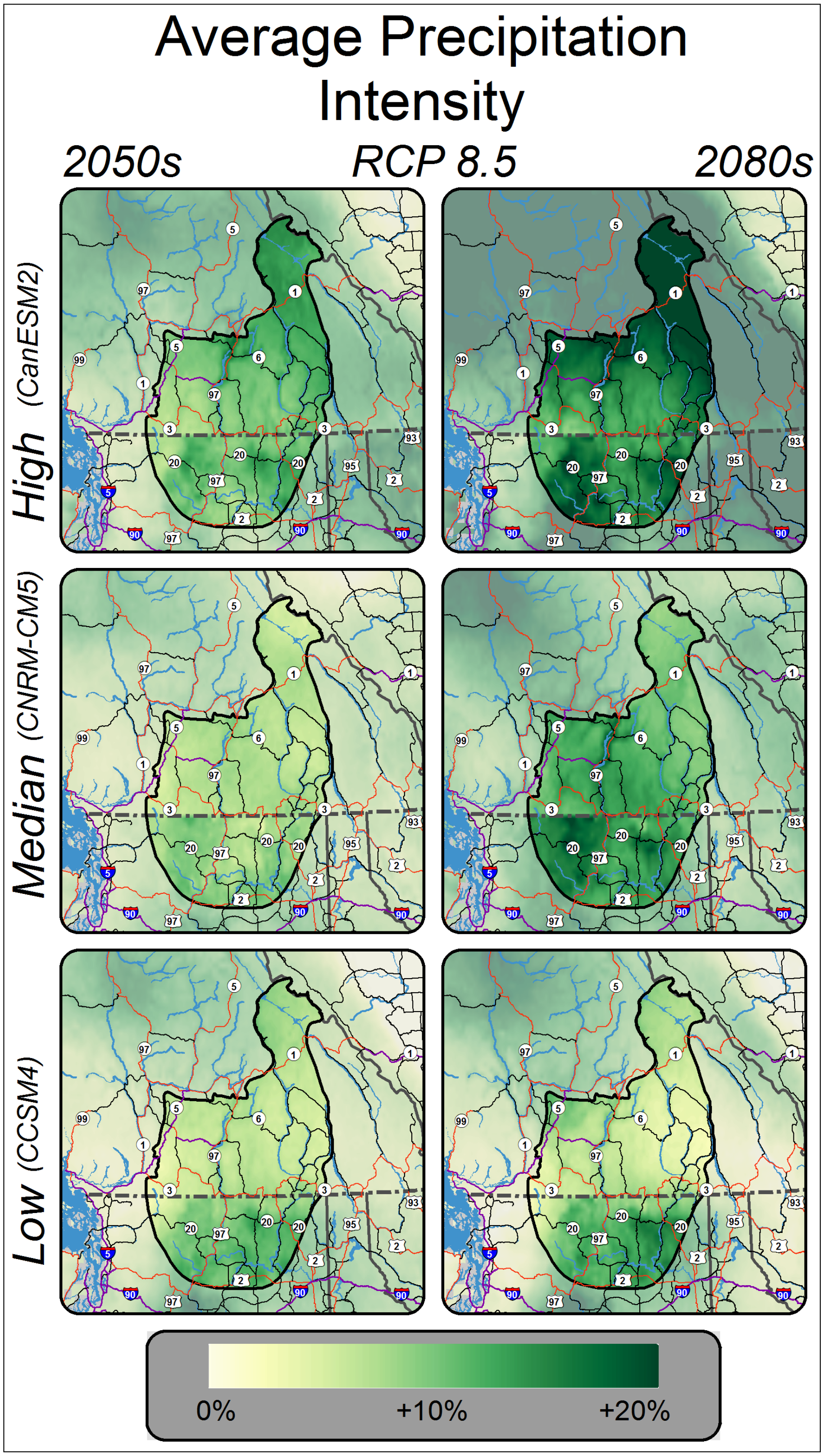
Appendix F.6f. Number of Heavy Precipitation Days

iii) Extent: Washington-British Columbia Transboundary Region



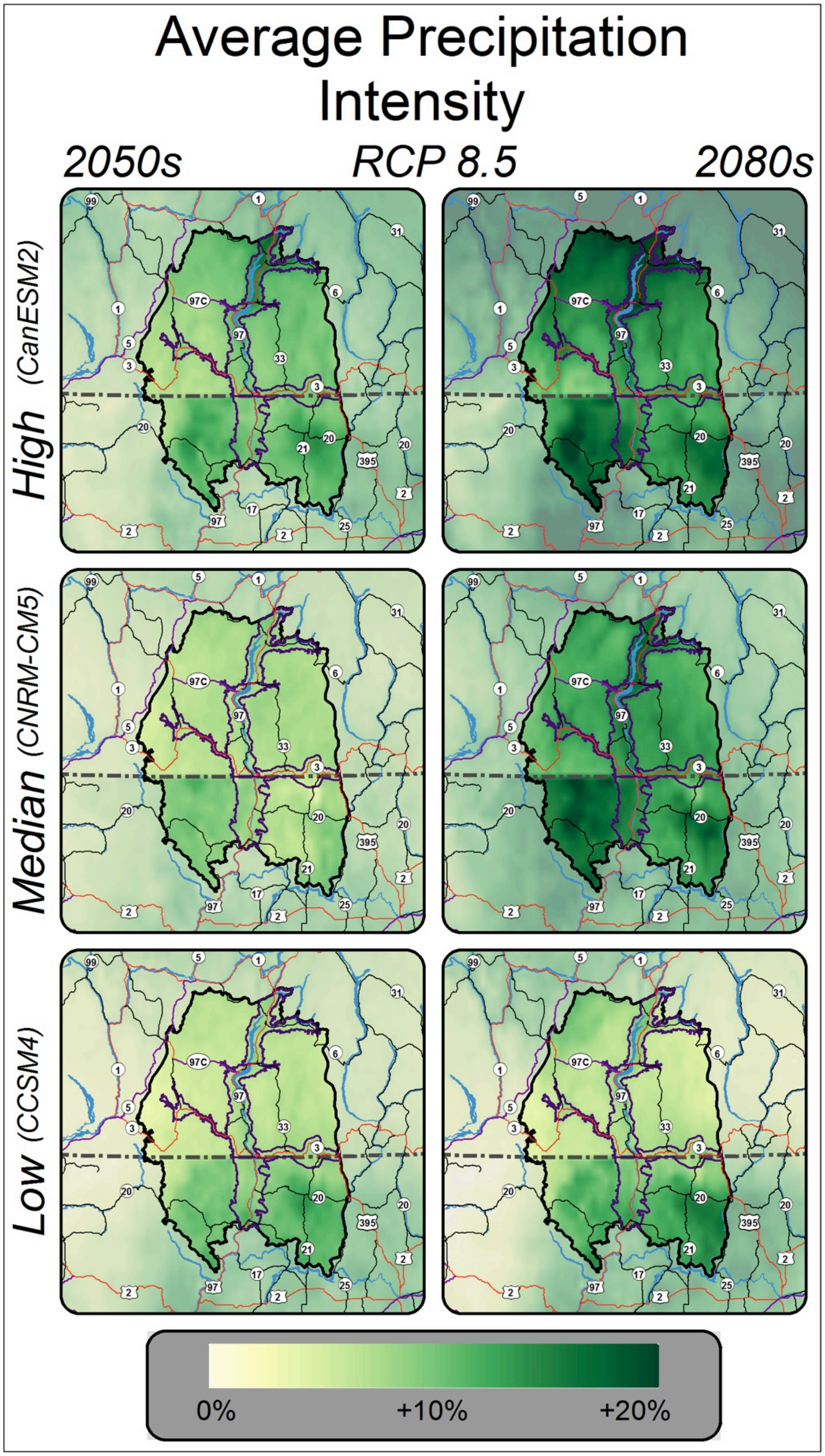
Appendix F.6g. Average Precipitation Intensity

i) Extent: Okanagan Nation Territory



Appendix F.6g. Average Precipitation Intensity

ii) Extent: Okanagan-Kettle Region



Appendix F.6g. Average Precipitation Intensity

iii) Extent: Washington-British Columbia Transboundary Region